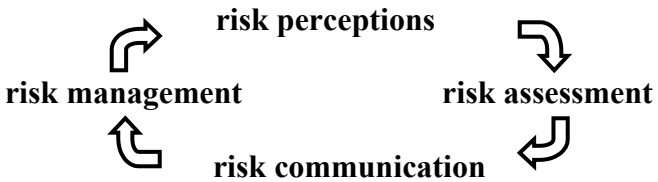
Chapter 1: Definitions

A logical introduction to an introductory text should include a basic definition of the field. In the case of risk analysis, this task is more challenging than you might expect. The field abounds with various and sometimes conflicting definitions. If we consider some of these definitions, we may gain a better insight to the nature and dynamics of this field. Risk analysis has many dimensions, and this chapter considers not only risk assessment, but also risk perceptions, risk communication and risk management, all of which are essential to the overall task of risk analysis. Together, these components form a cycle of ongoing refinement in all aspects of risk analysis (see figure 1). It may start with risk perceptions motivating our risk assessments, which need to be communicated in order to manage the problem. Depending on our outcomes of managing the risk, perceptions may be changed and the cycle may continue again. To be sure, there can be more complex cycles and interactions. However, the key point here is that an understanding of all the components is essential for analyzing risks.

FIGURE 1. CYCLE OF RISK ANALYSIS



Terms and Concepts:

risk
risk analysis
    epidemiology
    toxicology
risk assessment
    hazard identification
    dose-response assessment
    exposure assessment
    risk characterization
risk communication
    cognitive versus planning models
risk management
    "de minimus non curat lex"

1A. Defining Risk

Webster's dictionary gives us a fair picture when it defines **risk** as:

the possibility of suffering harm or loss.

In the first part of this definition, "possibility" suggests the work of statisticians. In the last part, "harm or loss" suggests the work of various health professionals (if we took a broader view, we could also include engineers, ecologists, and various other scientists).

Perhaps most interesting, however, is Webster's use of the word "suffering." Notice that we could drop this term from the definition and still have a workable guide (i.e., "the possibility of harm or loss"). However, its inclusion suggests the work of psychologists, sociologists, or medical practitioners -- how else would we measure "suffering"? Furthermore, perhaps a few lawyers would have some ideas on how to measure suffering! In any event, the underlying message here should be clear: the study of "risk" should always be multidisciplinary. Even the simplest definition shows us the formidable multiple challenges we face.

In 1983, the National Research Council provided a more formal definition of risk (1). Paraphrased, they defined risk as:

the probability and magnitude of a hazard.

A closer look at this definition shows it to be consistent with Webster's dictionary, but it uses a language more in keeping with the working professionals in the field. For example, magnitude is defined as the “seriousness” of a hazard, which most certainly can include suffering. The 1983 definition is one of the most referenced and therefore should be viewed as a standard definition.

The practical definition of risk, however, depends on who is using the term. One simple exercise can help reveal additional insights into use of the term "risk." By using a thesaurus, we can arrive at synonyms for this term (actually, it is quite easy with a thesaurus on a computer program). If we find secondary synonyms for each of the initial list of synonyms, it can reveal even more surprises. Consider the short list in Figure 2.

Figure 2. **SYNONYMS FOR THE TERM “RISK”**

possible	power	gamble
achievable	talent	game
skill	fortune	sport

Note some interesting synonyms: talent, gamble, and even sport! As used by the insurance industry, risk is the amount an insurance company stands to lose. Ultimately, risk is tied to money, power, and prestige. If you are thinking in terms of dollars and I am thinking in terms of skill, it is easier to see why misunderstandings happen so frequently with this term. Therefore, let this be a warning to avoid miscommunication: the true meaning of risk ultimately depends on who is using the term.

1B. Defining Risk Analysis

After considering the definition of risk, we can now make a better effort at defining **risk analysis:**

a collection of approaches and disciplines
devoted to all aspects of risk issues.

This definition is deliberately broad and open, because the emergence of new scientific disciplines is sure to bring new insights to the nature of risk. As this term is used by most professionals and within the Society for Risk Analysis, the field includes: 1) risk assessment, 2) risk communication, and 3) risk management. Thus, our task must now be extended to include these subsets of risk analysis. In other words, risk analysis does more than simply predict risks. It should also *compare* risks, to aid in decision making. It should compare *measures* of risks, because there is often more than one way to measure the risk. Moreover, it should compare *methods* for measuring risks, because there is a range of scientific techniques for assessing a given risk. Ultimately, its purpose is to inform policy and to help make better decisions.

Given the broad range of disciplines involved in examining risks, this text should be seen as a complement rather than a substitute for more substantial studies in such areas as epidemiology, toxicology, and statistics. Nevertheless, it offers a perspective for interpreting developments in these respective fields. Some simplified definitions given below help illustrate this point.

1. **Epidemiology** is "the study of the distribution and determinants of disease in humans." As such, epidemiology tends to focus on the effects of risk (i.e., disease).

2. **Toxicology** is “the science of poisons.” As such, toxicology tends to focus on the cause of risk (i.e., poisons).

3. **Statistics** is the “analysis of quantifiable data to describe or infer the characteristics of a population.” Both epidemiology and toxicology make use of statistics to reach conclusions about the populations they examine.

In all fairness, epidemiologists, toxicologists, and statisticians would have an equally difficult time defining their professions Furthermore, cause and effect is ultimately a concern for all these fields. As we will develop further in chapter 2, risk analysis considers all of these professions to corroborate its conclusions.

A number of critical reviews of risk assessment have occurred since the 1983 NRC book, and they should be mentioned early on as extremely useful references. Among the most significant are:

1. Proposed Guidelines for Carcinogen Risk Assessment (2),
2. Issues in Risk Assessment (3),
3. Science and Judgment in Risk Assessment (4), and
4. The Report of the Presidential/Congressional Commission on Risk Assessment and Risk Management (5).

1C. Defining Risk Assessment

Risk assessment is defined as:

the characterization of adverse effects from exposure to hazards.

Probably the simplest example of this characterization is to say "the risk of cancer from exposure to this chemical is *greater than one in a million*." Actually, such characterization should, at a minimum, include not only probabilities, but also uncertainties and the analytic models used to assess adverse effects. Analytic models come from the various areas of toxicology, epidemiology, and statistics, as well as a wide and growing range of natural sciences.

More formally, risk assessment traditionally includes four steps defined below: hazard identification, dose response assessment, exposure assessment, and risk characterization.

1. Hazard identification is to determine whether a particular agent is causally linked to particular health effects. For example, does this chemical cause cancer? Specific adverse effects are also called hazard endpoints, which will be discussed further in chapter 2.

2. Exposure Assessment is to determine the extent of human contact with a harmful agent (this is especially useful both before and after the application of regulatory controls). For example, after the Clean Air Act revisions are put into place, will the exposure of the average citizen to a given chemical be 50% of the allowable standard?

3. Dose-Response Assessment is to determine the relationship between the magnitude of exposure and the probability of occurrence of health effects in question. For example, will one ounce of a given chemical kill 50% of laboratory mice?

4. Risk characterization is to describe the nature and magnitude of human risk, including its uncertainty. For example, will a given chemical cause cancer deaths in anywhere from 3 to 100 people in Los Angeles over the next 20 years?

Risk assessment typically provides the following outputs:

1. it characterizes the expected health effects;
2. it estimates the probability (risk) of those health effects;
3. it estimates the number of expected cases;
4. it suggests an acceptable concentration from the standpoint of risk.

Much has been written on these components (6), and we will consider more of this in the coming chapters.

1D. Defining Risk Communication

Risk communication is defined as:

an interactive exchange of information and opinions
among individuals, groups, and institutions regarding risk.

There are several key points within this definition:

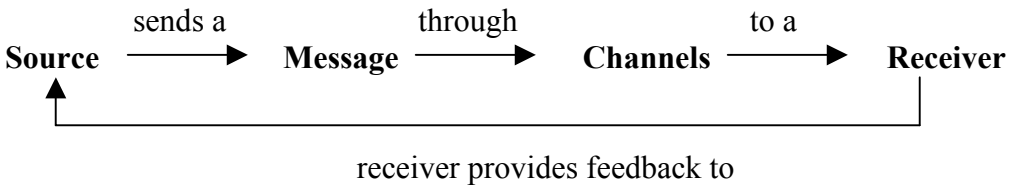
1. Risk communication is *interactive.* It is not simply a one-way conversation from the scientist to the public.

2. Risk communication includes *opinions.* Risk assessments will always contain uncertainty, so the opinions of all the participants should be part of this communication.

3. Risk communication may include *far more than two people*. While communication between any two people may be the easiest to visualize and is a critical basis for analysis, there are many more combinations when we include various groups and institutions.

There is some controversy over the proper framework for viewing risk communication research. Some researchers have described two schools of thought: cognitive models and planning models. These two frameworks are by no means mutually exclusive. **Cognitive models** stress the perceptions and biases that people have for risk, and this text will examine these models**. Planning models** divide communication into four parts: a *source* transmits a *message* to a *receiver* through various *channels*.

Figure 3. PLANNING MODELS FOR COMMUNICATION



Sources and receivers can be individuals or groups. Channels include television, newspapers, public meetings, and a growing number of approaches. The most crucial point here is that good risk communication is more than a clever message -- it is an interactive exchange that depends on all the model elements.

Toward this end, it is useful to consider risk assessments from both a risk communication and risk management perspective. For example, figure 4 summarizes the kinds of questions that should be asked about risk assessments (7).

FIGURE 4. QUESTIONS TO ASK ABOUT RISK ASSESSMENTS

1. Is the source reliable?
2. What is the message? (Get past the presentation and to the facts).
3. How strong is the evidence overall?
4. Where can I get more information?
5. What do the numbers mean?
6. How does this risk compare to others? (Put the risk into context).
7. What actions can be taken to reduce risk?
8. What are the trade-offs?
9. What else do I need to know?
10. Does this information matter?

1E. Defining Risk Management

Risk management is defined as:

the evaluation, selection, and implementation of risk control actions.

Evaluation and selection refer to the *decisions* that are made from a risk analysis. Implementation refers to the *actions* that are part of risk management. Risk management makes use of tools from economics, engineering, administration, and the law to support efforts towards sound decisions and effective actions.

The outputs of a risk assessment are often used for regulatory decisions. Indeed, the major motivation for risk assessment has been federal legislation and executive orders. One of the early influences on the use of risk assessment to guide decisions can be seen in the EPA document, Unfinished Business: A Comparative Assessment of Environmental Problems (13). This document prioritized various environmental risks according to the best known assessments of their risk, and then compared that to the relative priorities found in existing programs. One of the fundamental conclusions of that report was that the priorities for managing environmental problems did not correspond to the assessed risks.

On closer examination, we can see a wide range of legal strategies for managing risk. Historically, some laws have suggested that any risk is unacceptable, while others have made use of the concept of "**de minimus non curat lex**" ("the law is not concerned with trivial matters"). In the case of de minimus risk, a major influence came in the Supreme Court decisions on the regulation of benzene. The court ruled that de minimus risk was somewhere "between 1 in a billion and 1 in a thousand". Some agencies have interpreted this to mean 1 in a thousand, while others have essentially split the

difference (1 in a million). The decision of the court, however, left unanswered a variety of questions. For example, if you add all our involuntary exposures to the "1 in a million" risks, 1000 chemicals would yield a risk of 1 in 1,000, which is a risk that the court considered significant. The appropriate follow-up is unclear. Furthermore, if we compare these risks to voluntary activities, there is a major discrepancy: parachuting has a fatality risk of about 4 in 100, professional stunt men a risk of 2 in 10, and climbing Mount Everest a risk of over 1 in 10.

After considering these different issues, it should be clear that regulatory decisions depend on far more than risk assessments. They also depend on the quality of communication that has developed, on the attitudes and perceptions of the participants, and on the engineering and other controls that are reasonably available to solve the problem. In other words, risk management depends on all the various aspects of risk analysis.

At the same time, risk management must also face various paradoxes that cannot be addressed by risk assessment or risk communication. For example, consider the following paradox:

If:
1. All risk is unacceptable, and
2. All alternatives are risky.

Then:
1. All alternatives will be rejected,
2. Nothing will be done,
3. Even risk reduction options will be rejected,
4. The risk could actually increase!

Thus, there will always be limitations in using risk assessments for policy decisions. For example, risk assessment is usually only one aspect of policy decisions. Moreover, every risk analyst must acknowledge the judgments that are part of their conclusions. Incidentally, this would include a clear set of definitions they use for the terms "risk" and "risk analysis." For example, it is even possible to consider the risks in non-quantitative ways (9).

In the wake of all these developments, there are those who would classify environmental and occupational health as simply a subset of other professions (8). To avoid the fate of being subsumed by emerging disciplines, we need to consider the context of risk analysis (10). Building on our previous discussion, there is a list of questions to ask about any risk assessment project in its early stages. Of course, many more questions may be generated depending on the responses to these questions.

1. Who are the key participants in this risk assessment? Be sure to consider:
   a. the client
   b. agencies
   c. private corporations
   d. other consultants
   e. citizens groups

2. Since definitions of risk can vary, consider how risk is defined:
   a. by the client;
   b. by the relevant agencies (e.g., by the law); and
   c. by any other significant participants in the process.

   Answering these questions may be as simple as obtaining relevant documents or simply asking relevant individuals. However, it may also involve listening carefully to the language being used during discussions, or by observing local coverage by the media. All of these issues will be developed further in the text, but it is important at this point to look for varying interpretations. If possible, look for a consistent and reasonable definition of risk that is already part of the project. If not, insist on using a reasonable definition of your own. The 1983 definition mentioned earlier is a suitable standard. A thoughtful and reasonable definition of risk may raise your credibility early in the process, but more importantly it may clarify the expectations of the participants for the analysis.

3. Is this issue truly in need of a risk analysis?

   Would the results of the risk analysis have any effect on the decision? If so, is this more an issue of risk assessment, risk communication, or risk management? Of course, these answers may have a profound influence on the rhetoric, strategies, and interpretation.

4. What are some of the immediate uncertainties for this risk?
   Is the project adequately staffed and funded to resolve these uncertainties?

5. What are the key information sources for this risk?

Refining the analysis:

As the term is normally used, a screening risk assessment uses relatively simple models and limited data. In place of missing data, we typically require many assumptions and conservative default values. A refined assessment would therefore require more data, more sophisticated models, fewer assumptions, and fewer default values. This raises an important question: how refined can a risk assessment be? Ultimately, there may be no limit to the degree of refinement, because: 1) there is no end to the amount of data we can gather; and 2) there is seemingly no end, at least in our era, to the degree of sophistication in model development.

Therefore, this textbook takes a somewhat different approach. We assume that virtually all risk assessments can be thought of as screening risk assessments, because all of them can be refined by obtaining more data and using more sophisticated modeling. Moreover, none can predict risk with absolute accuracy. For example, in predicting cancers, virtually none can indicate with absolute precision the exact individuals who will be affected, precisely when it will happen, and precisely where it will happen.

On the other hand, some risk assessments are undoubtedly much more refined than others. Uncertainties can be substantially lowered. Furthermore, emerging techniques and disciplines will continue to refine our risk assessments. In this spirit, a section of the text entitled "refining the analysis" will be added to the end of each chapter. "Refining" is viewed here more as an ongoing process than an endpoint.

Perhaps the better question is: what is the appropriate level of refinement? The best answer is that it depends on the problem that is being assessed. In the forward of this book, the example of a snowy day was used. If I need to decide whether to where a coat outdoors, merely seeing the snow is enough for my decision (please note: for those rugged souls who would chose to brave the snow without a coat, please bear in mind -- I'm from California). However, if we were debating the existence of global warming, we would most certainly need more refined data and models. As one well respected analyst put it, "make the analysis as simple as possible, but no simpler" (11).

Therefore, if a screening risk assessment is good enough to help make the decision, then screening is all we need. The California EPA put screening risk assessment into perspective when they observed that "the purpose of this approach is to optimize the use of resources and perform a detailed risk assessment only when it is warranted" (12).

Finally, the value of a screening risk assessment to risk management can be seen if we consider the sheer magnitude of agents involved. While that number is ultimately unknown, it is widely believed that the total number of chemicals in and on earth is equal to many millions (14). There are billions of people potentially exposed, and even one exposure could potentially cost many lives, not to mention the tremendous environmental, financial, and social impacts.

Simply put, there are not enough trained professionals to perform a comprehensive and highly

refined risk assessment for all the potential agents and exposures that may occur. There may never be. The time and energy of the most highly trained experts is best spent in the ongoing refinement of the field and in the most refined assessments. As impressive as these refined assessments can be, they do not resolve the much bigger problem of countless agents and exposures.

Enter the philosophy of a screening risk assessment. As long as professionals are trained to interpret the numbers appropriately, we can rule out insignificant exposures and refer potentially harmful exposures to the appropriate professionals. Certainly we can take early corrective action as the law dictates. Nevertheless, as the field of risk analysis becomes more sophisticated, we run a greater risk of losing the generalist practitioners who can play an absolutely vital role in risk management.

The American Industrial Hygiene Association has underscored many of these principles in their position paper on risk assessment (15). For example, they support the use of an iterative approach to risk assessment, where screening approaches represent earlier steps of risk assessments. While supporting the use of default assumptions in a screening risk assessment, they also stress that these defaults must be well-defined. In addition, they take the position that risk assessment often falls short of providing definitive or uncontroversial answers, which is why there is a need for risk communication and risk management. Finally, they emphasize that risk assessment should be understandable to all stakeholders, including all of the potentially exposed populations. As we shall see in our later chapters, agreement among the scientists (even if it does occur) is simply not enough.

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 1A

1.The dictionary definition of risk takes "suffering" into consideration.

2.The dictionary definition of risk suggests a concern with statistics.

3.The dictionary definition of risk is concerned with harm.

4.The dictionary definition of risk suggests a multidisciplinary approach.

5.There is one definition of risk in which there is universal agreement.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: Module 1B

1.Risk management is a step in risk assessment.

2.Risk communication is a step in risk management.

3.Risk analysis is concerned with only one thing: to predict risks.

4.Ultimately, the purpose of a risk analysis is to help make decisions.

5.Risk analysis includes epidemiology and toxicology within its study.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: Module 1C

1.Risk assessment includes exposure assessment.

2.The magnitude of a risk is ultimately expressed in the hazard identification step.

3.Risk characterization cannot occur without the other steps of a risk assessment.

4.The adverse effects that can be studied with risk assessment are also called hazard endpoints.

5.Exposure assessment cannot occur without all the other steps of a risk assessment.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: Module 1D

1.An example of risk communication is a scientist's one-way presentation of the results of a risk assessment.

2.Risk communication should not allow for the opinions of the uninformed.

3.Risk communication can involve more than two people.

4.Cognitive models and planning models are two approaches to risk communication.

5.Risk perceptions can influence the communication process.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: Module 1E

1."De minimus non curat lex" means that the law will be concerned with even trivial matters.

2.Decision making is a critical part of risk management.

3.Actions to solve problems are also a critical part of risk management.

4.Risk management can benefit from a consideration of all the other aspects of risk analysis.

5.Regulatory decision often depends on risk assessments.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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Updated online information at http://www.csun.edu/~vchsc006/469/0.html

Chapter 2: Hazard Identification

A **hazard** is any condition or physical situation with a potential for an undesirable consequence, such as harm to life or limb. In other words, it is the source of a risk. **Hazard assessment** is an analysis and evaluation of the physical (e.g., radiation), chemical (e.g., organics) and biological (e.g., microbial) properties of a hazard. **Hazard identification** determines whether a particular agent is causally linked to particular health effects. In hazard identification, we are using the tools of toxicology, epidemiology, and statistics to help identify and understand these hazards.

Risk analysis seeks to *integrate* this information for a more comprehensive view of the risks. Toward this objective, the material presented here emphasizes the interactions of these fields, and the reader is encouraged to seek additional coverage of each field provided by references at the end of this chapter.

Terms and Concepts:

Hazard
- hazard assessment
- hazard identification

toxicological issues
- risk group
- experimental group, test group
- control group
- experimental dose range

epidemiological issues
- relative risk vs. attributable risk
- prospective study vs. retrospective study
- ecological fallacy
- confounders, bias
- incidence vs. prevalence
- standard mortality ratio

statistical issues
- null hypothesis
- statistical error (types 1-5)

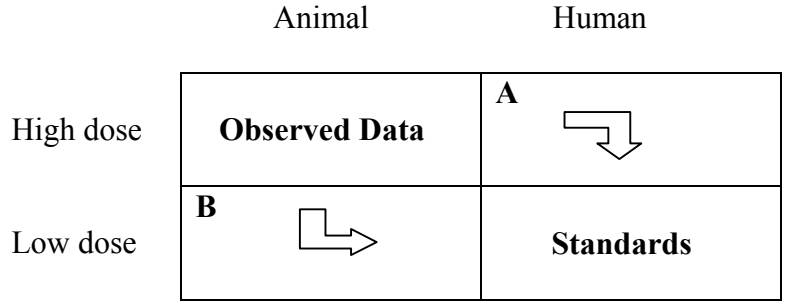
classification of carcinogens (EPA, IARC)

2A. Defining Toxicological Concepts

The role of toxicology is to provide information on the hazards of chemical agents.
A more thorough coverage of toxicity is well covered in other texts (5). However, the issue that serves as the starting point to this discussion is one of animal studies. While human subjects are possible, it is especially true that extensive data are available from animal subjects. The fundamental question here is: how do we integrate the different risk assessment studies into a coherent and consistent picture?

The heart of the problem is illustrated in Figure 5. Our observed experimental data is concentrated in high doses to test animals. Toxicology and epidemiology work independently to yield the required information about low doses in humans.

FIGURE 5. EXTRAPOLATION FROM OBSERVED DATA TO STANDARDS



A = e.g., epidemiological methods to extrapolate high to low doses in humans.
B = e.g., toxicological methods to extrapolate low doses from animals to humans.

Throughout this text, the following terms will follow their traditional definitions. It should be noted that these definitions can vary, and clarification may be required in how these terms are used within a given risk assessment.

A **risk group** is the group for which a risk assessment is being conducted. Typically, this is a human population.

A **test group** (also called an experimental group) is a study group (for both toxicological or epidemiological studies) used to ascertain the risk to the risk group. For example, we may use rats as a test group in order to learn more about risks to humans, the risk group. The risk to the test group must be compared to a **control group**.

An **experimental dose range** includes the dose in the test group. If this dose is higher than the dose to the risk group, we must extrapolate the results to the risk group. This raises issues that are addressed later in the text.

Various bioassays of chemical carcinogens may be performed, as listed below.

1. The structure of a chemical can be informative with known carcinogens, and can guide other assays.
2. Various in vitro short-term tests can be performed. No in vitro test has identified all carcinogens, so a battery of tests is usually needed. Bacteria mutagenesis, such as the Ames test, is frequently used within this category.
3. DNA repair rates can be measured by radiographic techniques. If cells repair DNA attacked by mutagens, we can measure the rate of that repair as an indicator of mutagenicity.
4. Mammalian mutagenesis can be tested in isolated cells.
5. Sister chromatid exchange can be good for epigenetic carcinogens (epigenetic is when there is no evidence of direct interaction with the genetic material; genotoxic is when there is direct evidence of genetic effects).
6. Cell transformation, when genetic material is transferred from one cell to the next, constitutes an in vivo test. In vivo bioassays include tumor induction in mice, and chronic bioassays can be done at lower concentrations for longer periods of time.

An initial critique of animal studies should include, at a minimum, these three considerations:

1. gross differences in weight over time
2. gross differences in survival over time
3. control data may be unstable

The first two considerations may be due to acute toxicity. If we are extrapolating animal results to lower (subacute and chronic) doses in humans, we want to remove any interference due to acute toxicity. The third consideration is relevant if we have difficulty finding a suitable control group for comparison. Beyond these considerations, there is a logical hierarchy of data selection:

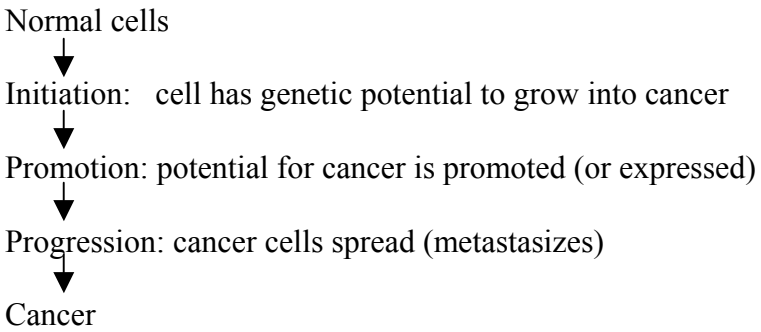
1. human data has the highest priority, followed by
2. appropriate routes of exposure (i.e., the test group has the same as the risk group),
3. lifetime exposure, and
4. lifetime observation.

Finally, some classic uncertainties to animal studies include:

1. accounting for multiple routes of exposure, or uncertain doses;
2. interactions such as synergism, antagonism, and potentiation;
3. classification of subjects as exposed or non-exposed, and getting a correct diagnosis;
4. extrapolation between species or to lower doses; and
5. matching the control to test groups, and test to risk groups.

Turning our focus on cancer, there are a number of aspects that need to be clarified early in the analysis. Cancer can be viewed in stages as outlined in figure 6. A **complete carcinogen** would be able to cause all the required changes for cancer to occur, while a **partial carcinogen** causes only some of the required changes.

FIGURE 6. CANCER STAGES



Experimentally, cases are defined by a so-called **hazard endpoint** (a specific, observable change that constitutes the definition of a physiological or metabolic effect). Cancer endpoints may include the following sites: lungs, colon, breast, pancreas, prostate, stomach, bone marrow (leukemia), and of course many others. Equally important is the wide range of **non-cancer** hazard endpoints: cardiovascular, respiratory, neurological, immunological, mutagenic (hereditary disorders), reproductive (fertility), teratogenic (birth defects), and damage to various organs (e.g., kidneys, liver).

Undoubtedly, the definition of hazard endpoints will continue to be refined, even to the molecular level. For example, the last decade has seen a greatly improved understanding of the "modes of action" of chemical carcinogens (1). The U.S. EPA's guidelines provide a framework for using such information. According to the guidelines: "While the exact mechanism of action of an agent at the molecular level may not be clear from existing data, the available data will often provide support for deducing the general mode of action. Under these guidelines, using all of the available data to arrive at a view of the mode of action supports both characterization of human hazard potential and assessment of dose response relationships" (2).

2B. Defining Epidemiological Concepts

In essence, the role of epidemiology is to provide information on the risks to human subjects. The difference between epidemiology and risk analysis is one of scope: risk analysis is an interpretation of epidemiological information on not only the causes but also the *action* needed to manage the risks. The essence of epidemiology is the fourfold table, shown in Figure 7.

FIGURE 7. THE FOURFOLD TABLE

		Disease (cases)	
Exposure		+ (cases)	- (non-cases)
+ (exposed)		**A**	**B**
- (not exposed)		**C**	**D**
		A + C = Total cases	B + D = Total non-cases

A + B = Total exposed

C + D = Total not exposed

Several definitions can be derived from the fourfold table:

1. Risk to the exposed (i.e., probability in the test group), or
   Pt = A / (A+B)
2. Risk to the unexposed (i.e., probability in the control group), or
   Pc = C / (C+D)
3. **Relative Risk** = Pt / Pc

4. **Attributable Risk** = Pt - Pc

Relative Risk assumes risk is *proportional* to underlying risk, and a RR > 10 is a very strong association.
Attributable Risk assumes risk is *independent* of underlying risk, and represents a distinctly different measure.

Both measures are constantly used, but the operational difference between relative and attributable risk can be seen in the hypothetical example of figure 8.

FIGURE 8. RELATIVE RISK VERSUS ATTRIBUTABLE RISK

Consider the following cancer deaths from exposure to **chemical X:**

	cancer deaths	no cancer deaths	total
Exposed	**110**	**890**	1000
Not exposed	**10**	**990**	1000

RR = (110/1000) / (10/1000) = .11/.01 = 11
AR = .11 - .01 = .1

Consider the following cardiovascular deaths from exposure to **chemical Y:**

	cardiovascular deaths	cardiovascular deaths	total
Exposed	**900**	**100**	1000
Not exposed	**500**	**500**	1000

RR = (900/1000) / (500/1000) = .9/.5 = 1.8
AR = .9 - .5 = .4

For chemical X in figure 8, a relative risk of 11 is a strong association, and (.1 * 1000) = 100 deaths attributed to chemical X.

For chemical Y in figure 8, a relative risk of 1.8 is a weak association, but (.4 * 1000) = 400 deaths attributed to chemical Y.

For passing laws to control chemical Y, many more deaths might be saved, *provided the risk is substantiated.* Unfortunately, a relative risk of 1.8 is weak. The analyst can chose from at least two actions (i.e., to control or not control the exposure), and each action can be followed with at least two possible outcomes (i.e., the risk is substantiated or is later ruled out). The analyst therefore faces at least four scenarios with weakly defined risks as shown in figure 9.

FIGURE 9. FOUR SCENARIOS FOR DECISION-MAKERS AND POORLY DEFINED RISKS

	Risk is later substantiated	Risk is later ruled out
Took action to control exposure	**heroic**	**wasteful**
Did not control exposure	**murderous**	**economical**

Hazard identification studies are done in different population settings, each with its own set of limitations. For example, clinical settings usually involve acute, reversible effects, with (A + C) in figure 7 dominating the population. Experimental studies may not involve humans. Epidemiological studies are typically analyzed after the fact (often in occupational settings).

Epidemiological studies are generally divided into two types of studies: retrospective studies (also called case-control studies) and prospective studies (also called a cohort study). A **prospective study** considers individuals from 2 groups: exposed and not exposed. By "exposed" we mean this group has been exposed to a suspected risk factors we wish to study. Both of these two groups, called cohorts, are then followed over time to determine any differences in the rate at which disease develops. In particular, the rate we wish to find is the **incidence,** defined as the number of new cases of a disease in a population over a period of time. This rate should be contrasted with **prevalence**, defined as the number of existing cases in a population who have the disease at a given point (or during a given period) of time.

Retrospective studies consider individuals from two very different kinds of groups: cases (having the disease or condition of concern) and controls. These two groups are then analyzed for possible differences in exposure. **Cross-sectional studies** are designs where measurements of cause and effect are made at the same point in time. Only the prospective studies can give us the incidence, and only incidence is appropriate for risk assessments. Retrospective studies may provide interesting information and useful support, but the rates they provide cannot be used as estimates of risk.

An epidemiological value that can be useful to risk assessments is the **standardized mortality ratio (SMR)**, defined as the ratio of observed deaths in a population (an exposed group) to the expected number of deaths (derived from rates in a standard population). Analogous to relative risk, SMRs are also adjusted for age and other potentially relevant factors such as gender or race.

An unfortunate mistake made all too often is called the **ecological fallacy**. It is a conclusion from a correlation between variables that were derived from data grouped in social aggregates (i.e., ecological units). The fallacy is that conclusions from aggregate groups will hold for individuals. Suppose, for example, we discovered that Californians as a group will attend more movies and have greater cancer rates than New Yorkers. The fallacy is that this ignores the Californians who never go to movies and the New Yorkers who are avid movie-goers. In order to sort out the influence of movies on cancer (a dubious activity to begin with), we would need to

study each individual for their residence, movie habits, and cancer outcomes, so that the correlation is by individual habits.

In a larger sense, epidemiology is constantly searching for **confounding factors.** This refers to variables that may cause differences between cases and controls that do not reflect differences in the variables of primary interest. For example, suppose we find higher cancer rates in Californians than in New Yorkers, and higher consumption of milk in Californians than in New Yorkers. In keeping with the previous discussion, this study has examined residency, milk consumption and cancer rates at the individual level to avoid the ecological fallacy. Suppose, however, that Californians also have higher cigarette consumption rates than New Yorkers. Is the higher cancer rate in Californians (a hypothetical example, to be sure!) due to milk consumption or cigarette consumption? This is a confounding variable, and unless we have examined cigarette smoking at the individual level (along with milk consumption and cancer rates), we will have a difficult time sorting out these variables. Other confounding variables for this question might also include age, race, occupation, and so on.

2C. Defining Statistical Concepts and Tests

In the hazard identification stage, a relatively simple way of determining a statistically significant difference between the test group and the control group is the following equation (also given in Appendix 2):

$$z = \frac{Pt - Pc}{\sqrt{pq\left(\frac{1}{Nt} + \frac{1}{Nc}\right)}}$$

where:
Nt = total number in test group
Nc = total number in control group
Xt = cases in test group
Xc = cases in control group

Pt = Xt / Nt = risk to test group
Pc = Xc / Nc = risk to control group
p = [Xt + Xc] / [Nt + Nc]
q = 1-p

Incidentally, Xt corresponds to A, and Xc corresponds to C in the fourfold table in module 2B. This equation can only be used when Nt*p, Nt*q, Nc*p, and Nc*q are all greater than 5 (i.e., part of a normal population). Most documented studies are large enough to satisfy these conditions.

Z is sometimes called the "critical ratio", and Z is used to calculate the p-value. A p-value is the probability that the results are <u>not</u> statistically significant. If the p-value is less than .05, we generally conclude that the results <u>are</u> statistically significant. These values are further described in appendix 2. With all the elements in place, we can now try a sample problem

Sample problem: Suppose 20 of 100 test rats (exposed to a suspected carcinogen) develop cancer and 6 of 100 control rats also develop cancer. Are the differences between these groups statistically significant?

Answer:

Nt = 100
Nc = 100
Xt = 20
Xc = 6

Pt = 20/100 = .2
Pc = 6/100 = .06

p = (20+6)/(100+100) = .13
q = 1 - .13 = .87

Nt*p = 100 * .13 = 13
Nt*q = 100 * .87 = 87
Nc*p = 100 * .13 = 13
Nc*q = 100 * .87 = 87

Since the above 4 values are all greater than 5, we have verified normality. Finally, we fill in the entire equation:

$$z = \frac{.2 - .06}{\sqrt{.13 * .87 * (\frac{1}{100} + \frac{1}{100})}}$$

$z = 2.94$

The table in appendix 2 shows that when z = 2.94, the p-value is between .006 and .001 (although it is closer to .001). If the p-value = .05, then we say that the difference is significant with 95% confidence. In this problem, we are at least 99.4% confident that the difference is statistically significant.

2D. The role of statistical error

Given the diversity of issues in interpreting risk assessments, it is instructive to consider the various fundamental types of error in statistical measures. Such a consideration of error can, of course, help evaluate the validity of the risk assessment, but it can also help interpret the results from a policy perspective.

In classic statistical theory, the **null hypothesis** states "there is no difference between the experimental group and the control group**." Type 1 (or alpha) error** is defined as a false rejection of the null hypothesis. Thus, the burden of proof is on the scientific investigator to show that there ***is*** a difference between these two groups, thus establishing a significant effect. In the language of statistics, we must *reject* the null hypothesis in order to establish that an effect is statistically significant. Thus, the rejection of a null hypothesis results in acceptance of scientific theory. Related to this are **false positives**, which are results that show an effect when one is not there.

Since scientists do not want to accept false theories (which would threaten the very integrity of science), our first concern is to minimize the chances of rejecting a null hypothesis and later discovering that the null hypothesis was true. In other words, accepted theories should pass the strictest standards, thereby preserving the integrity of science. In the language of risk, type 1 error tells us that we must *prove* something is unsafe.

This is contrasted with **type 2 (or beta) error**, defined as the false *acceptance* of the null hypothesis. Related to this are **false negatives**, which are results that show no effect when in fact one is there. Consider the consequences of type 2 error: if we accept the null hypothesis and state there is no statistically significant effect, what if we later discover that our conclusions were incorrect? We could miss opportunities for protecting public health! While scientists would be protected from making inappropriate claims of health effects when none exist, it is equally true that many more people could die before science finally has the statistical confidence to declare a health hazard.

Of course, we can decrease both type 1 and 2 error if we have more powerful studies with larger sample sizes and more sensitive tests, but many scientific issues are midstream, and all too many policymakers are in policy paralysis while waiting for stronger proof of an effect. In the language of risk, type 2 error reminds us that we must also consider proving that something is *safe*. This is at the heart of so many important policy issues. Activists are more concerned about type 2 errors, while classical scientists and corporations that often must devote huge resources to diverse public issues are more concerned about type 1 errors. When a scientific issue is fraught with uncertainty, this simply highlights the distinction between these two errors and creates a fundamental impasse in public policy.

This impasse has been the subject of great scrutiny by scholars and professionals over the years, and more attention has been devoted in recent times to **type 3 error**, defined as "asking the wrong question." For example, we may have looked at cancer when the real problem is reproductive hazard. If we had asked a well focused question, we may have minimized errors of

the previous categories. All too often, agencies are prone to type 3 error because their focus is often predicated by law.

Similarly, **type 4 error** emphasizes use of the wrong method, particularly compelling in light of the previous discussion about different inputs to risk analysis. For example, we may be using chemistry to solve a social problem, or vice versa. Consider this: who is in a position to diagnose this problem? In a word: generalists. Unfortunately, as specialists use the tools of their discipline on an array of risk issues, their focused expertise belies the ignorance they may have for other specialties. It has often been said that the greatest development of recent scientific research is multi-disciplinary research. This speaks to the heart of type 4 error, although a multi-disciplinary group is not the same as an *integrated* group of generalists. The Tower of Babel, after all, was engineered by a multi-disciplinary group!

Finally, **type 5 error** is reaching the wrong policy conclusion, sometimes described as the right diagnosis followed by wrong medicine, or as good science followed by *bad policy*. Scientists who are reluctant to be involved in public policy may be valuable in the lab but sit in frustration while poor policy unfolds. Science groups with a social agenda often come under sharp criticism, but this approach speaks to the heart of type 5 error.

Closely related to all of these errors is **statistical bias**, which refers to any systematic distortion away from the "truth." For example, **selection bias** refers to differences in baseline characteristics because of the way participants were selected or assigned. It is also used to mean that the participants are not representative of the population of all possible participants.

Performance bias refers to differences in the care provided to the participants in the comparison groups other than the intervention under investigation. **Attrition bias** (also called exclusion bias) refers to differences in withdrawals from the study. **Detection bias** (also called ascertainment bias and measurement bias) refers to differences between the comparison groups in outcome assessment.

2E. EPA and Other Classifications of Carcinogens

It is possible to integrate our previous discussion into an overall classification system. The U.S. EPA has traditionally classified carcinogens into five basic categories that reflect the weight of evidence from toxicological and epidemiological studies (3). Proposed guidelines may eventually replace this approach with more extensive procedures (2). However, the traditional classification approach is a useful starting point for considering the integration of previous information.

Group A refers to human carcinogens based on 3 criteria: 1) no identified biases in existing studies; 2) confounders have been ruled out; and 3) chance is ruled out (i.e., statistically significant results). In general, several independent studies are required to reach group A designation. There should also be a strong association, a reasonable dose response relationship (i.e., reduced exposures should lead to reduced cancers).

Group B refers to probable human carcinogens. In this category, the evidence ranges from "almost sufficient" to inadequate. Within group B is B1, which is credible evidence, but alternative explanations have not been ruled out. B2 refers to few pertinent data, but does not exclude chance, bias, or confounders. "Sufficient evidence" from animal studies may include: 1) increased incidence in multiple strains; 2) multiple experiments; or 3) unusual features (e.g., incidence, tumor, or age of onset). Regarding mutagenicity data, no short term tests are allowed, and negative tests do not rule out a chemical.

Group C refers to possible human carcinogens. Limited evidence may come from a single species, strain, or experiment. Inadequate dosage, duration, follow-up, survival, numbers, or reporting may occur, or benign tumors may be the only ones discovered. In some cases, short terms tests or known chemical and physical properties can raise C to B2, or D to C.

Group D includes all agents not classified. There may be inadequate animal evidence of carcinogenicity.

Group E refers to no evidence of carcinogenicity. In this group, there must be no evidence in at least two adequate animal tests (e.g., different species), or both an epidemiological and animal study must be completed.

EPA also provides classification of **germ cell mutagens** with three categories: sufficient evidence, suggestive evidence, and limited evidence. Classification of **developmental toxicants** (teratogens) is extremely difficult, and there are currently no EPA guidelines for weight of evidence. Instead, safety factors are used (explained later in this text). Organ and tissue toxicants, which may kill a large number of cells, affects the general function of tissues and organs. Safety factors are also used for these toxicants. The highest priority is given to data from human studies. Of these studies, the highest priority is given to studies with the appropriate route of exposure, lifetime observation, and lifetime exposure (in that order).

The International Agency for research on cancer (IARC) publishes a classification system as shown in table 3. Note the similarities with the EPA classification system.

FIGURE 10. IARC CLASSIFICATION SYSTEM FOR CARCINOGENS

Categories	Weight of evidence
1. Human carcinogen	Human data
2a. Probable human carcinogen	Limited human data and sufficient animal data, or sufficient animal and other relevant data
2b Possible human carcinogen	Limited human data, or sufficient animal data, or limited animal and other relevant data
3 Not classifiable	Data do not fit into any of the above groups
4. Probably not human carcinogen	Lack of carcinogenicity in human and animal studies

A final note: toxicology and epidemiology can never give us absolute information about chronic risks. However, extrapolation from these two different methods may enhance the validity of hazard identification and the larger picture of risk analysis.

Refining the analysis:

In refining a hazard identification, we can ask the following questions.

1. Are there multiple studies for the risk being assessed? If so, can we account for apparent differences in the identified hazards?

   In order to best access such information, we begin with **MEDLARS**, which is an acronym for the MEDical Literature Analysis and Retrieval System. It is a collection of databases managed by the National Library of Medicine. **MEDLINE** is perhaps the best-known of the MEDLARS databases. It is a system for finding health-related journal articles. MEDLARS contains **TOXNET**, which is an acronym for the TOXicology data NETwork. TOXNET contains **IRIS, TRI, HSDB**, and other health-related databases. **IRIS** is an acronym for the Integrated Risk Information System, which contains risk assessment information on specific chemicals. More information on TOXNET is given in the appendix.

2. Have the studies been reviewed by state, national, or international organizations?

   Again, the value of TOXNET is that most of the studies have gone through some type of review, and quite often very extensive review by some of the most respected scientists in the world. In a screening assessment, there is no need to "re-invent the wheel" (i.e., to conduct your own extensive review of the literature) if the literature has already done so.

3. Have the studies been examined for type 1 through type 5 errors?

   If studies have not been reviewed, you may have no choice but to conduct your own initial review. How do various studies stand up to the points raised in section 2A-2C? Are there consistencies in the literature regarding the hazard, or are there contradicting results?

There are, of course, more refined tests available in statistics, epidemiology, and toxicology. For example, multiple regression analysis can tell us more about the multiple variables and their statistical relationships to potential hazards. Epidemiologists conduct various kinds of prospective and retrospective studies. Molecular toxicology can redefine the definition of both dose and response.

Nevertheless, even the most refined methods suffer from uncertainty (e.g., limited availability of data to run the models). These themes will continue to be developed in future chapters. Like the snowy day looming outside the window, we have decisions to make, and the decision itself should drive the need for data.

Ultimately, the critical question may not be "is this a hazard?" This may seem ironic given the material presented in this chapter, but the real question may be "*do we proceed with this risk analysis*?" At first, these two questions may appear to be essentially the same question. After all, if an agent does present a hazard, we should proceed with a risk analysis to better understand that hazard. Conversely, if an agent does not present a hazard, there is no apparent justification for a risk analysis.

However, most situations are not so clear cut, because most types of hazard identification do not yield absolute yes or no answers. For example, if we identify a "possible carcinogen," we could complete an entire risk analysis using animal data extrapolated to humans, only to find at a later date that the agent does not cause cancer in humans. This could represent a waste of resources (risk management issues) and needlessly alarm the public (risk communication issues). On the other hand, assessing the risk implications when the hazard is unclear may also provide insights on where the research could go next. For an example of this approach, see Juutilainen et al. (8).

Given the competing interests that are so commonly found in risky issues, types 3, 4, and 5 error play a greater role. In asking whether we should proceed with the risk assessment, we are deliberating on whether it will solve any problems or enlighten any decision. These are more qualitative concerns, but they require hard thinking about the real underlying purpose of a risk analysis. Expert judgment ultimately must play a role in sorting out these thorny issues (4).

Other issues include: assessing exposures and hazards simultaneously (9), and hazard identification of mixed exposures (10). Ideally, a hazard would be clearly identified in humans, thus justifying an exposure assessment. However, a study of this type is highly unlikely due to the difficulty of obtaining adequate data (6).

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 2A

1.No in vitro test has identified all carcinogens.

2.Mammalian mutagenesis cannot be tested in isolated cells.

3.Cell transformation can occur when genetic material is transferred from one cell to the next.

4.The rate of DNA repair can act as an indicator of mutagenicity.

5.Epigenetic carcinogens refer to when there is no evidence of direct interaction with the genetic material.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 2b

1.The risk of the exposed group is equal to the number of diseased, exposed individuals divided by the total number of exposed individuals.

2.The risk of the non-exposed group is equal to the number of diseased, non-exposed individuals divided by the total number of non-exposed individuals.

3.The relative risk is equal to the risk of exposed group minus the risk of the non-exposed group.

4.The attributable risk is equal to the risk of exposed group divided by the risk of the non-exposed group.

5.Hazard identification studies are done in different population settings, each with its own set of limitations.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 2c

1.A risk group is the group for which a risk assessment is being conducted.

2. An experimental group is a study group (toxicological or epidemiological) used to ascertain risk to the risk group.

3.An experimental dose range includes the dose in the experimental group.

4.A test group is also called an experimental group.

5.The experimental group must be compared to a control group.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 2d

1. Type 1 error refers to false acceptance of the null hypothesis

2. Type 2 error refers to false rejection of the null hypothesis

3. Type 3 error refers to asking the wrong questions.

4. Type 4 error refers to using the wrong method.

5. Type 5 error refers to good science followed by bad policy.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 2e

1.EPA Group A carcinogens refers to known human carcinogens.

2.EPA Group B carcinogens refer to possible human carcinogens.

3.EPA Group C carcinogens refer to probable human carcinogens.

4.EPA Group D carcinogens refer to unclassified agents.

5. EPA Group E carcinogens refer to no evidence of carcinogenicity.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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Updated online information at http://www.csun.edu/~vchsc006/469/0.html

Chapter 3: Environmental Fate

Consider a hypothetical molecule. Environmental fate modeling follows that molecule from the moment of its release to its ultimate outcome in the environment (1). Such models can range from relatively simple rating models to sophisticated numerical models (2). The objective of this chapter is to understand the building blocks to these models, and the reader is encouraged to follow up with the recommended references at the end of the chapter. We begin by defining basic concepts of environmental fate, and move to models of air dispersion, surface waters, and groundwater. We integrate these features by considering multi-media concepts and models.

Terms and Concepts:

- Environmental fate
  - transport
  - transfer
  - transformation
  - mass balance
  - background levels
- air dispersion
  - concepts
    - Eulerian
    - Lagrangian
  - models:
    - UNAMAP
    - Rollback, statistical
    - Gaussian plume
    - box and multibox
    - regional trajectory
    - physical
- surface water models
  - advection
  - molecular diffusion
  - turbulent diffusion
  - degradation and decay
- groundwater models
  - vadose zone
  - hydraulic conductivity
  - hydraulic gradient
  - porosity
- Partitioning, phases
  - Henry's law
  - Octanol partitioning
  - Organic carbon partitioning
- Model refinement:
  - rating models
  - analytical models
  - numerical models

3A. Defining environmental fate concepts

Environmental fate refers to the ultimate destination of contaminants released into the environment. The three major aspects of environmental fate models are:

1. **transport**, which is the physical movement of pollutants (e.g., wind, water flow);

2. **transfer**, which is the movement of pollutant through media (e.g., between water, air, and soil). In other words, multi-media models examine the transfer of pollution through the media of air, water, and soil. It seeks to answers the following question: if you release a chemical into the environment, where does it end up?

3. **transformation**, which is the change in physical or chemical structure in a pollutant. For example, oxidation, photolysis, and the chemical interaction of pollutants may transform the original chemical agent. Perhaps the best known example of transformation is photochemical smog.

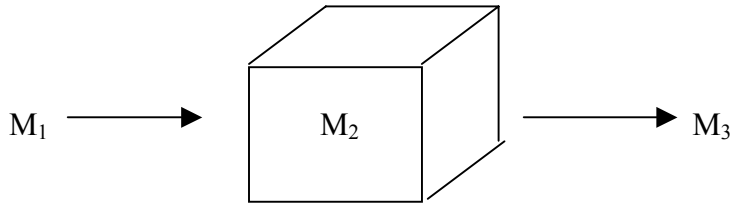
One of the first rules of environmental fate modeling is the primacy of real data. In other words, if the analyst has access to real data, this information takes priority. However, there are a number of valid reasons why real data may not be readily available.

1. The cost of obtaining usable data may be prohibitive for a given project.
2. The time needed to obtain the data may be an issue – for example, a decision may be required before adequate data are fully available.
3. Perhaps the best reason is timing. Planning may require decisions on a facility *before* it is ever installed. Literally, decisions must be made before real data are available.

Many environmental fate models are built on the concept of **mass balance** (also called conservation of mass). Consider the following variables for figure 11 below:

M_1 = mass entering compartment (i.e., all sources)
M_2 = existing mass (background levels that are already in the compartment)
M_3 = mass exiting compartment (i.e., all sinks)
M_t = total mass in the compartment

FIGURE 11. MASS BALANCE



$Mt = M_2 + M_1 - M_3$

A few introductory comments must be made about this model. First, the sources (represented by M_1) may include transformation and transfer as well as transport. Second, **background levels** are defined as the level of pollution present in any environmental medium attributable to natural or ubiquitous sources. Finally, the kinetics for each of these levels can vary significantly. For example, **zero order kinetics** means that M_3 does not depend on M_2. **First order kinetics** means that M_3 is proportional to M_2, and **second order kinetics** means that M_3 is proportional to the square of M_2.

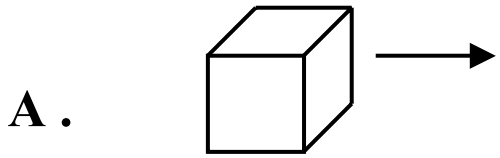
Another frequently used reference in environmental fate modeling is to **finite difference equations**. Differential equations are widely used to model chemical , physical, and biological phenomena. Unfortunately, these differential equations may become too large to solve through standard analytic calculus. In these cases, finite difference equations are used to approximate the solution. Thus, we often hear of finite difference models throughout the math modeling in environmental health. Their roots are in the solution to these complex differential equations.

3B. Defining air modeling concepts

Air quality models begin with a coordinate system (also called a frame of reference) that helps to identify the location and movement of pollutants. These frames of reference fall into two distinct categories. The first system, **Eulerian**, is fixed on the earth's surface, and can best be thought of as a map of pollutant location. In fact, most data are collected in this form. The Eulerian perspective is shown in figure 12. This traditional approach is better suited for describing topography, various atmospheric issues, and the movement of reactive pollutants from multiple sources.

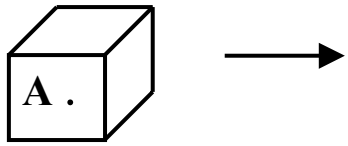
An alternative frame of reference, **Lagrangian**, is fixed on a parcel or puff of pollutant. The observer in this frame of reference always stays in the center of the puff. The Lagrangian perspective is shown in figure 13. An analogy to these two approaches is to consider a car being driven along a highway: a Eulerian perspective would be a pedestrian standing at the side of a road, while a Lagrangian perspective would be the driver inside the moving car. The Lagrangian frame of reference makes it easier to model diffusion and other effects. Lagrangian and Eulerian frames of reference can be converted from one form to the other, but unless the reader knows the original frame of reference, it may be difficult to follow the derivations for the assorted transport models.

FIGURE 12. EULERIAN PERSPECTIVE OF A MOVING COMPARTMENT



A = an observer from a Eulerian perspective
(outside the moving compartment,
fixed to the earth's surface)

FIGURE 13. LAGRANGIAN PERSPECTIVE OF A MOVING COMPARTMENT



A = observer from a Lagrangian perspective
(inside the moving compartment)

The movement of the compartment of air (sometimes called a parcel) is dependent on many variables. For an initial list, we should certainly include:

1. the horizontal and vertical velocity of the parcel as it exits a stack;
2. the temperature of the parcel as well as the surrounding atmosphere;
3. the wind speed in the area; and
4. the terrain in the area, including buildings as well as natural hills and valleys.

Each of these variables is in turn influenced by a number of other considerations. For example, velocity of the parcel may depend on the stack diameter. Temperature changes with altitude depend on the stability of the atmosphere. Wind speed tends to increase with altitude.

The types of models used for air modeling trace back to the EPA development of **UNAMAP** (Users network for applied modeling of air pollution). These models are divided into three categories:

1. Near Field (transport of pollutants from 0-50 km),
2. Intermediate Range (transport of pollutants 50-250 km),
3. Long Range (transport of pollutants over 250 km).

The uncertainty of transport models depends heavily on which category in which it falls. For example, *near field mod*els running at optimal levels tend to be accurate within a factor of 2 to 4, but under conditions of complex terrain, the accuracy may be only within 1 - 2 orders of magnitude. Complex terrain adds to uncertainty for various reasons, including:

1. channeling the flow of pollutants rather than simple diffusion;
2. mechanically induced turbulence, which is extremely difficult to model;
3. complex vertical gradients in wind speed and wind direction; and
4. various heating and cooling effects.

Intermediate range models carry even great uncertainty because of the more substantial travel time of pollutants, daily variations in weather, and the much larger terrain effects on transport. Of course, research continues to develop the accuracy of these models, and it is critical to use the right model for the right set of environmental conditions. In the absence of these considerations, the best approach is to assume conservative conditions and report the results as such.

Long range models, of course, have the same set of problems, but more attention has been devoted to these models with the legal mandates for issues such as acid rain. These models are generally accurate within a factor of 3 to 5.

3C. Air dispersion models

Rollback models originated with U.S. Clean Air Act. They are relatively simple models, and few resources are needed for them. They relate historical data (e.g., emissions and air quality) with future air quality by using linear relationships as follows:

$$Ci = B + \sum_{i} kiEi$$

where:

Ci = future concentration at point i
B = background level
Ei = emissions for point i
ki = proportionality factor for point I

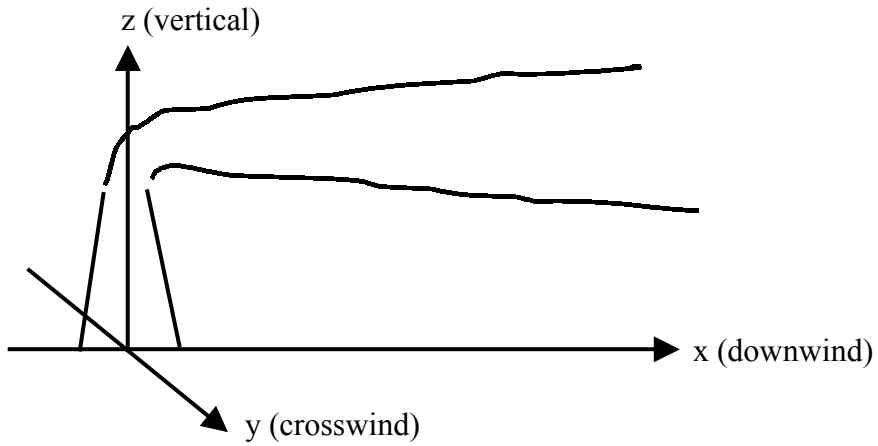
The proportionality factors represent mathematical constructs that bear no relation to environmental phenomena. In other words, they fit the data but have no physical meaning. A flaw with this approach is that these equations are valid only for the prevailing conditions of sources and emission levels. If another source is introduced, all the proportionality factors may have to be recalculated. As such, these models may be acceptable for screening air control strategies. However, after screening, more sophisticated models are generally required.

Various **statistical models** may also be used for air pollution modeling, and perhaps the most typical approach is through regression analysis. With this approach, variation in spatial distribution of pollutants can be investigated as a statistical task. The same criticisms for the rollback model apply to statistical models -- again, the statistical correlations may have no physical meaning, and the associations generally are valid for only the prevailing conditions. For example, if new sources move into the area, all of the associations may no longer be valid.

Gaussian plume and puff models are among the oldest and most preferred of models. They depend on the availability of realistic physical data on wind and diffusion. A large number and variety of current air transport models rely on the basic Gaussian equation. This approach can be especially suitable for non-reactive pollutants, and various models can account for such problems as turbulent diffusion, dry deposition, washout from rain or snow, and chemical transformation. One of the most commonly used Gaussian models is SCREEN, which can be accessed at this textbook's web site.

The Gaussian model recognizes that a plume traveling downwind will gradually expand and disperse. For example, figure 14 shows a stack emitting pollutants that are carried downwind (the x direction). As the plume travels further downwind it expands in both the y (crosswind) and z (vertical) direction. Due to dispersion in the y and z direction, the plume always has its highest concentration in the center of the plume and the lowest concentrations at the edges of the plume. The Gaussian model assumes that these concentrations can be described by a normal (i.e., Gaussian) distribution. The size of the plume is characterized by the standard deviation of the concentrations in the plume.

FIGURE 14. X, Y, Z COORDINATES FOR A GAUSSIAN PLUME MODEL



The fundamental Gaussian equation is given below.

$$\chi \equiv \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left[(y/\sigma_y)^2 + (z/\sigma_z)^2\right]\right]$$

where:

χ = concentration at any point in the x, y, z coordinate space (kg/m^3)
Q = emissions (kg/sec)
u = average wind speed (meters/sec)
σ_y = ("sigma-y") standard deviation of dispersion in the y direction (meters)
σ_z = ("sigma-z") standard deviation of dispersion in the z direction (meters)
x = distance downwind (meters)
y = distance crosswind (meters)
z = vertical direction (meters)

The values of sigma-y and sigma-z depend on how far the plume has traveled in the x direction. In other words, as the plume travels further downwind, the plume will grow in width and height. Values of sigma-y and sigma-z have been determined empirically by plume studies under previous environmental conditions. The values depend on many variables, and especially on the stability of the atmosphere. Stability is normally rated from A to F, where A is the least stable and F is the most stable of environments. An A stability would result in a plume that is widely dispersed in the y and z direction, thus resulting in lower average concentrations at any given distance. For a more extensive example, see the web page for this book to determine sigma-y and sigma-z under different conditions.

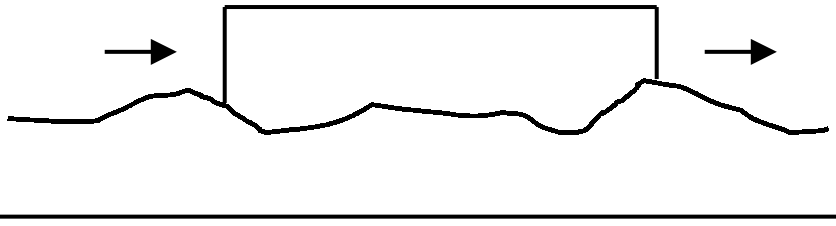
There are, of course, fundamental limitations with all Gaussian models. First, they depend on the availability of accurate data. The average wind speed and the most accurate values of sigma-y and sigma-z are always significant issues. Second, their validity drops with stable atmospheres such as inversions. For example, if an inversion were located just above the plume, it could interfere with the dispersion of the plume. Third, these models are especially vulnerable to effects of complex terrain. For example, the turbulence created by complex terrain can interfere with our assumptions about even dispersion.

For all these reason, Gaussian dispersion models tend to assume conservative values for dispersion parameters and the effect of wind speed. More refined models must account not only for a broad range of physical issues that affect transport, but also for additional issues of transfer and transformation.

Box and multibox models are so named because they are based on the concept of a very large "box" of air. This so-called box may be extremely large but is conceptually no different than the compartments discussed at the beginning of this chapter (see figure 15). The bottom of the box is the terrain, the top of the box is usually the first inversion layer, and the remaining areas of the box are usually geographically defined areas (e.g., mountains or incoming prevailing winds). Multi box models give better resolution and allow for interactions at surfaces of boxes.

It is usually assumed that the air in box is well mixed (concentrations are given by total mass divided by total volume of the box), and reactions are allowed in each box. This approach has been used to explain smog in L.A., California with some success. The primary disadvantages of box models are that no vertical air motion is allowed, and it is sometimes difficult to solve box models efficiently. In the final analysis, turbulent atmospheres are not boxes.

FIGURE 15. BOX MODELS



Regional trajectory models usually cover larger regions instead of just urban pollution. For example, transport across the western U.S. has been studied using these models. Other work has covered transport of acid rain, and some work has been done with very large smog episodes with these models. This approach focuses on mass conservation over time. For example, consider the following Lagrangian equation:

$dM / dt = - (a + b + c) * M$, where:
a, b, c = dry removal, wet removal, and chemical conversion
M = mass inside the moving compartment

This approach is good for only a limited number of sources, or if multiple sources are treated as if they were only one source. It can be more accurate than Gaussian models for complex terrain, or terrain larger than 50 km in radius. They are simpler than multibox models, but they can be sensitive to errors in wind speed and direction.

Physical models such as wind tunnels are good for ultra-complex real life problems. For example, the turbulent effects of large buildings or mountains can be studied with small scale models. Such an approach has been good for optimizing stack height or design, and for the selection of monitoring stations.

3D. Environmental fate models for rivers, watersheds, and groundwater

River Models

Surface water models must account for a variety of additional issues. For example, **advection** refers to the horizontal movement by currents (e.g., the velocity of pollutants moving downstream). Advection rate is normally incorporated into models by the following equation.

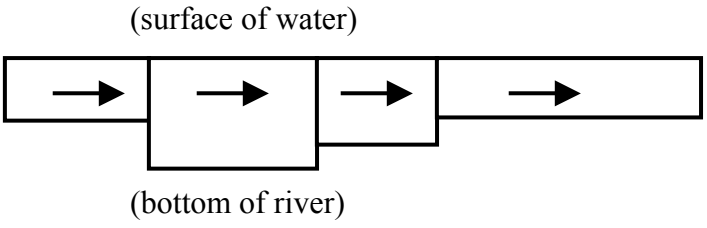
J = CV where:

J = flux density
C = concentration of pollutant in water
V = velocity of water

While advection accounts primarily for movement downstream, the movement in other directions is primarily by diffusion (i.e., spreading or mixing). **Molecular diffusion** refers to the random thermal movement of molecules, while **turbulent diffusion** refers to mixing that is encouraged by turbulence (e.g., when sugar is stirred into coffee). Both diffusion and advection are reduced when pollutants are adsorbed to sediments at the bottom of the river. A variety of other issues may be incorporated into river models, including: **media transfer** (to air and soil), **degradation and decay** (of chemical compounds), **transformation** (to different chemical states), and non-point as well as point source contributions.

The primary conceptual basis for these models is, once again, mass balance. This is exemplified by the **EXAMS** model (the Exposure Analysis Modeling System). In this model, a river is envisioned as a series of uniformly mixed "**reaches,**" which are essentially very large compartments. Figure 16 is a cross sectional view of a river in four reaches, although the model can include up to 32 different segments. Estimated concentrations are based on uniform dilution in each reach and assumed rates of physical and chemical removal. Each reach can simulate up to 28 different substances. EXAMS has a database of toxic substances and also allows for the definition of new substances and new ecosystem conditions.

FIGURE 16. A RIVER AS A COMBINATION OF REACHES



EXAMS uses differential equations based on mass balance. In addition to basic accumulation of pollutants within a reach, the model can also account for biological transformation and transport. Environmental conditions may remain constant or vary monthly. The program produces output tables and simple graphics describing exposure, fate, and persistence.

The major uncertainties for river models generally fall into four categories:

1) transport of sediments which have adsorbed some of the pollutants,
2) biological transformations,
3) complex flow conditions (e.g., tidal forces), and
4) variable rates of pollution introduced into the river.

An example of a very refined model is SERATRA (an acronym for SE-diment RA-dionuclide TRA-nsport). This model accounts for sediment movement, but still has its own set of challenges: it requires extensive input data, extensive computer time, and cannot handle reversible flow (e.g., tides). There are a variety of river models, and new ones continue to be developed (3).

Watersheds

A **watershed** is defined as water flowing over land towards surface water. The primary conceptual basis for these models is derived from the study of hydrology, focusing on runoff patterns and rates of evaporation and percolation. Soil erosion also plays a major role because of sediments dissolved and adsorbed. The uncertainty behind all of these models is assumptions about chemical transport and data input.

EPA has selected **HSPF** as the model of choice for HW risk assessment. HSPF is an acronym for Hydrological Simulation Program—Fortran. The model was developed in the early 1960's as the Stanford Watershed Model, and numerous refinements have been added since then. HSPF simulates long term processes on land, in streams, and in impoundments. The model contains hundreds of process algorithms developed from theory, laboratory experiments, and empirical relations from watersheds. The program can simulate more than one area discharging to more than one river reaches or reservoirs. HSPF simulates the following conditions:

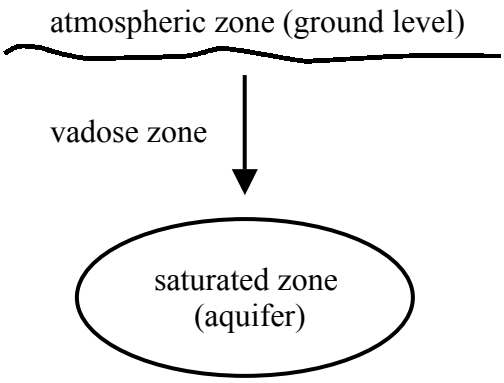
surface runoff	evapotranspiration	sediment
biochemical oxygen demand (BOD)	temperature	pH
ground-water recharge	fecal coliforms	plankton

Meteorologic records are required for HSPF. Tillage practices, point sources, and (or) pesticide applications may be required for water-quality simulation. Physical measurements and related parameters are required to describe the land area, channels, and reservoirs.

Groundwater

The primary conceptual basis for these models is the unsaturated or **vadose zone**, which is the region between the atmospheric and saturated zone. The saturated zone is generally an aquifer composed of sand and gravel with water saturating the pores. The movement of contaminants in the vadose zone is subject to adsorption and desorption in this zone. Older models of groundwater pollution relied on statistical methods to describe the risk that a pollutant would reach the groundwater. More modern approaches rely on mass balance approaches.

FIGURE 17. ZONES IN GROUNDWATER MODELING



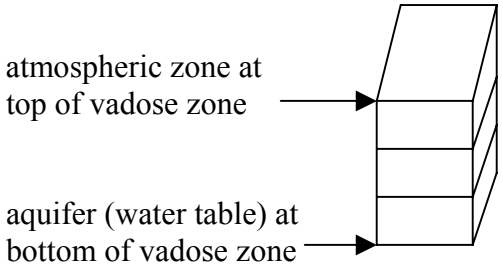
Many conditions can affect movement through the vadose zone, such as water solubility, organic carbon in soil, anions at ambient pH, and high precipitation rates. This also requires, at a minimum, some basic information on the chemical and physical properties of the pollutant. Fortunately, handbooks are available with this information (4). Also, biodegradation rates must be carefully studied, because they can have significant effects on environmental fate models (5). Once again, handbooks are available with this information (6). However, the environmental conditions must be well understood, because they can significantly affect rates of biodegradation (7). Notice the theme that we see throughout risk analysis: the more detailed information we have, the more accurate predictions we can make as to environmental fate.

The movement of pollutants, once they have reached the saturated zone, is experimentally measured by the **hydraulic conductivity (**measured in centimeters per second). Movement is also affected by the **hydraulic gradient** (i.e., the difference in water pressure), and the **porosity** of the soil (percentage of water within the total volume of the aquifer).

VLEACH is an acronym for "Vadose zone LEACHing model." It is a screening model for organic contaminants moving through the vadose zone. The VLEACH program itself is public domain and downloadable off the internet, and the documentation includes installation instructions, a user's manual, and some theoretical background. VLEACH is one-dimensional, meaning that it examines only the vertical movement towards the groundwater. VLEACH is also a finite difference model, meaning that it is built on partial differential equations. These equations simulate the following processes: 1) vapor-phase diffusion (evaporation of the pollutant), 2) liquid-phase advection (movement with water), 3) solid-phase sorption (attachment of the pollutant to soil), and 4) equilibration among the above three phases.

A key concept of VLEACH is that it simulates leaching in distinct **polygons.** For example, figure 18 shows a single rectangle located at the top of the vadose zone (i.e., the land surface). This same rectangle (i.e., a polygon) is then extended downward through the entire vadose zone (i.e., from the land surface to the water table). VLEACH is actually able to simulate multiple polygons, and each polygon may be divided into multiple layers, or cells. For example, figure 18 shows one polygon with three cells. Each polygon may differ in terms of soil properties, recharge rates, depth to water, or various initial conditions.

FIGURE 18. A SIMPLIFIED POLYGON IN A VLEACH MODEL



Conceptually, this approach should appear similar to the box models in air quality models. The contaminant in each cell is partitioned among three phases: solid, liquid, and vapor. Time is divided into discrete steps (e.g., a year). During each step, each of the three separate processes (diffusion, advection, and sorption) takes place, and each cell is equilibrated after each time step according to distribution coefficients. The modeling results in an overall assessment of groundwater impact weighted for each of the polygons. Reports are generated for concentrations in soil, groundwater, and vapor phase over time and for selected depths.

Some important assumptions of VLEACH that make it a screening type model include the following:

- homogeneous soil properties within each polygon;
- constant water recharge rate;
- VLEACH has a limited database of soil and chemical properties;
- no degradation or production within cells;
- The polygons can simulate only a single layer of soil profile.

A model that goes beyond VLEACH is **SESOIL** (an acronym for "SEasonal compartment model for long-term pollutant fate and transport in the unsaturated SOIL zone"). SESOIL is also a one-dimensional vertical transport screening-level model, and is also available as a public domain model. It is generally viewed as the standard for vadose zone models. For example, SESOIL goes beyond VLEACH in the following ways.

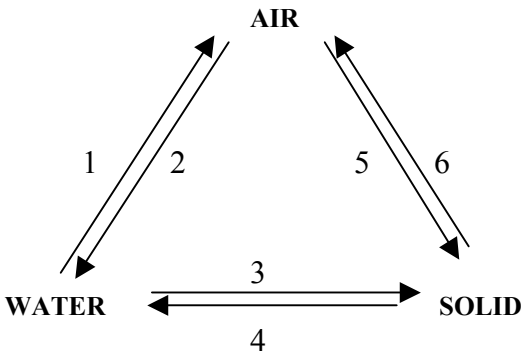
It allows up to four soil layers (each layer having different soil properties), with each layer containing up to 10 sublayers.
It simulates seasonal climatic variations.
It automatically generates of up to 100 years of weather data
It allows depth variable and time variable initial concentrations.
It has an extensive database of soil parameters and chemical properties.

In addition to volatilization, sorption, and advection, SESOIL can account for cation exchange, biodegradation, hydrolysis and chemical complexation. It also models surface runoff and erosion at the ground surface. SESOIL produces monthly results for each layer and sub-layer of the model. SESOIL estimates these components on a monthly basis for up to 999 years of simulation time. It can also be combined to estimate the average concentrations in ground water.

3E. Multi-media issues

Historically, environmental health has been concerned with components of the environment: air, water, food, and so on. Of course, we have always realized that these components are interlinked, but stories abound to remind us of how powerful these linkages are. For example, an EPA study in Philadelphia found the largest single source of air pollution (not counting the collective contribution of cars) is the wastewater treatment plant! Undoubtedly, this may also be true for most metropolitan areas. Extending this concept to the task of pollution treatment, we can see how processes can simply chase pollution in a circle:

FIGURE 19. THE TREATMENT PARADOX
(treatment can move pollutants from one media to another)



1 = wastewater treatment releases organics into the air.
2 = wet scrubbers remove gaseous pollutants but may produce water pollution.
3 = drying of wastewater sludge may produce solid waste.
4 = garbage disposals send food wastes to wastewater.
5 = air filters remove aerosols but may produce solid waste.
6 = incineration reduces solid waste but may produce air pollutants.

This concept also raises important questions about multi-media pollution.

1. Which media is most serious? For example, should we be devoting more resources to air, or water, or food? And how does our answer change depending on the attributes of a given pollutant?
2. Which treatment methods work best? A treatment method that simply exchanges the media in which pollutants reside is less effective than one that provides for final disposal or transformation of a pollutant. From this view, how can we reevaluate treatment methods?
3. Which policies work best? Most environmental policy has focused on one media at a time. From a multi-media standpoint, how can policy-makers be better advised on the consequences of legislative output?

We are still very much in the process of answering these questions, but together they form the basis of studying environmental fate and exposure assessment. For example, if we wished to expand upon Figure 19, we could add the role of plants and animals. The food chain models represent a higher level of complexity. The conceptual basis of these models is the solubility and root uptake of various pollutants. These types of models are a relatively recent endeavor, and are subject to many sources of uncertainty. For example, volatilization from soil surface may exceed root uptake as critical pathway, and many current models do not account for this phenomenon. In addition, animal metabolism after eating is often undocumented by these models.

Multi-media transfer is the mathematical modeling of pollution movement through the media of air, water, and soil. That is, it seeks to answers the following question: if you release an arbitrary chemical into the environment, where does it go?

The simplest start to this question is to consider the concept of partitioning between phases. **Phases** refer to the solid, liquid, and gaseous states of a compound. **Partitioning** is the ratio of concentrations between two phases. These ratios are constant for a given compound, so for modeling purposes we are interested in these so-called partitioning coefficients.

Perhaps the simples example of this is air-water partitioning. This is accomplished by **Henry's law**, which states:

K = X/P **where:**

P = vapor pressure of a gas
X = mole fraction of a gas in liquid
k = Henry's law constant (air-water partitioning coefficient)

Continuing along these lines, water-organic partitioning can be studied by **Octanol water partitioning coefficient**, which states:

P = Co / Cw **where:**

P = octanol-water partitioning coefficient
Co = concentration of chemical in octanol
Cw = concentration of chemical in water

If P is high, then the chemical is more fat soluble (e.g., DDT). P is also a predictor of biomagnification in the food chain. For example, log-log plots of P versus bioconcentration of various organic chemicals show a linear relationship.

Another commonly used value is the **organic carbon distribution coefficient**. Organic carbon is measured by combusting a sample of soil and measuring the carbon dioxide produced. The organic carbon content of soil (as opposed to the inorganic carbon, such as carbonates), is the fraction that is most responsible for binding with pollutants. This relationship to the binding of pollutants in soil is represented by the following.

Koc = Cs / Cw **where:**

Koc = organic carbon distribution coefficient
Cs = concentration of chemical attached to soil
Cw = concentration of chemical in water

Thus, with some relatively simple inputs on the character if pollutant chemicals, we can predict with reasonable accuracy the ultimate fate of these agents (9). Programs mentioned earlier (e.g., EXAMS) incorporate this information into their output. The consequences for most known chemical agents in this type of analysis is that the food chain may be primary source of exposure to organics.

Refining the analysis:

There are three basic categories of models that represent increasing degrees of refinement. First, **rating models** are based on subjective ranking of geological (distance, depth, and permeability) and pollutant factors (solubility and toxicity). Because of the subjective judgments that are used in rating models, they tend to be viewed as having the lowest degree of refinement.

The second and more refined category is **analytical models**, based on simplified math equations. An example of this is the gaussian equation for air dispersion, which can be determined through the use of a single equation, or may have minor additional modifications. Because of the mathematical simplifications of complex phenomena, analytic models are viewed as more refined than rating models, but not necessarily the highest degree of refinement.

This is distinguished from the third and most refined category, **numerical models**, which have far more complex equations (e.g., partial differentials of water movements). These models tend to require more data, they tend to be adaptable to a wider range of problems, and they are viewed as having the least amount of model uncertainty.

Unfortunately, many analysts fall into the trap of assuming that the most refined models are always the best. However, it is vital to remember that a model should be appropriate to the *decision*. If a rating model clearly demonstrates that there are no concerns for environmental movement of a pollutant, there may be no need to proceed with other models. Moreover, we cannot make use of many numerical models if the required data are not available!

Another fallacy is that the recommendations of a rating model are inherently less reliable than numerical models. Again, a numerical model without the required data is not reliable at all! Moreover, while the rating models may be more subjective than numerical models, they are also more conservative. Thus, a conclusion of no significant environmental movement from a rating model is bolstered by its highly conservative assumptions. In the spirit of refinement, if a rating model suggests concerns with movement, we would be motivated to use analytic models. If an analytic model suggested unacceptable concentrations, we would be motivated to gather the extensive data for numerical models.

Finally, these models can be refined by being combined for more extensive output. For example, a water model can be tied with a food chain model, or an air model can be combined with a geographic information systems model (8).

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 3a

1.Transfer is the physical movement of pollutants.

2.Transport is the movements of pollutant through media (e.g., between water, air, and soil).

3.Transformation is the change in physical or chemical structure in a pollutant.

4.Environmental fate includes transport, transfer, and transformation.

5.The environmental fate of photochemical smog can include transport, transfer, and transformation.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 3b

1.Near field transport of pollutants covers 0-50 km.

2.Intermediate range transport of pollutants covers 50-250 km.

3.Long Range transport of pollutants covers distances over 250 km.

4.Lagrangian frames of reference are fixed on the earth's surface.

5.Eulerian frames of reference are fixed on a puff of pollutant.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 3c

1.Rollback models relate historical data with future air quality by using proportional relationships.

2.Regression analysis describes variation in spatial distribution of pollutants by statistical approaches.

3.The validity of Gaussian models drops with stable atmospheres.

4.Regional trajectory models usually cover larger regions such as transport of acid rain.

5.For box models, the bottom of the box is the terrain, and the top of the box is usually the first inversion layer.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 3d

1.The EXAMS model describes a river as a series of uniformly mixed "reaches."

2.EPA selected HSPF as the model of choice for watershed assessment

3.One example of a groundwater model is MITRE.

4.Conditions that affect risk to groundwater include: water solubility,organic carbon in soil, anions at ambient pH, long half lives, and high precipitation rates.

5.Relative to the other models, SERATRA requires extensive input data.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 3e

1.Rating models are based on subjective ranking of geological and waste factors.

2.Analytical models are based on simplified math equations.

3.Numerical models generally require more data.

4.Henry's law addresses water-soil partitioning.

5.Octanol partitioning addresses air-water partitioning.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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For more information:

Crosby D.G., Environmental Toxicology and Chemistry, Oxford University Press, 1998.

Online information at: http://www.csun.edu/~vchsc006/469/0.html

Chapter 4: Exposure Assessment

Using tools from the previous chapter, we can predict where pollutants may transport, transfer, and transform in the environment. From the standpoint of human health, however, this is not enough. The next logical question is: how will humans be exposed? If, for example, a pollutant is adsorbed to deposited sediments at the bottom of a river, the chances for human exposure are more limited than if, say, it is airborne and inside a crowded room. This chapter addresses a series of questions continuing into the next chapter that ultimately asks: what is the dose to the target organ? The reader is encouraged to follow up with readings in molecular biology, some which are referenced at the end of this chapter. First things first, however, and we introduce exposure and dose concepts in this chapter.

Terms and Concepts:

exposure
- predictive exposure assessment
  - micro-environments
  - Monte Carlo
  - exposure scenario
  - induction, latency. effective exposure
- reconstructive exposure assessment
  - biokinetic modeling
  - target organ
  - biotransformation (catabolic, anabolic)
  - active metabolite
  - biomarkers

dose
- delivered dose, absorbed dose
- administered dose, applied dose
- intake, uptake
- retention, organ burden
- integral organ burden
- retention half-life
- benchmark dose
- maximum tolerated dose
- body burden

probability distribution functions

accuracy vs. precision
- data quality objective
- limits of detection,
- variability vs. uncertainty

4A. Exposure Assessment Methods

Exposure is defined as:

the amount of an agent available at the exchange boundaries of an organism and available for absorption

Examples of "exchange boundaries" include skin, lungs, and digestive tract. In other words, exposure assessment must account for **routes of exposure** (ingestion, inhalation, and skin absorption). In using the phrase 'available for absorption," it is important to distinguish exposure from dose. Exposure is *before* absorption and dose is *after*. Before we can address dose (which is discussed in section 4C), we must address exposure. Exposure assessment must, at a minimum, estimate the magnitude, frequency, duration, and routes of exposure. Exposure assessment is important to both toxicological and epidemiological studies (1,2), and is often the most sensitive issue in risk assessments at low-level exposures (3,4).

There are two basic approaches to exposure assessment. The first is **predictive exposure assessment**, which forecasts exposure *before* they occur – this is typically accomplished by assuming a variety of default values. The second approach is **reconstructive exposure assessment**, which estimates exposures *after* they have occurred (this approach is discussed further in section 4d).

The first example of predictive exposure assessment is the **microenvironment method**, which requires personal measurement of an individual's immediate environment. This is generally accomplished by direct methods such as air sampling. This approach is often used in occupational studies with strategically located monitors. The micro-environment method is a summation of exposures as represented below:

$$E = \sum_i fi\, Ci = f_1C_1 + f_2C_2 + f_3C_3 + ... + f_iC_i$$

where:

E = exposure
i = micro-environments
f = fraction of the total time of exposure
C = pollutant concentration

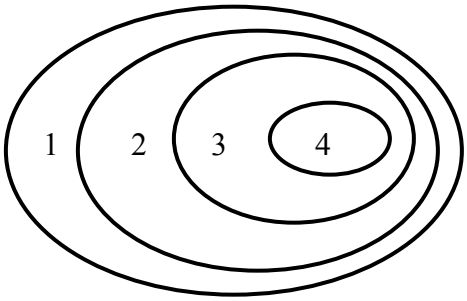
With the highly mobile populations of most developed countries, ambient environmental quality is usually a poor predictor of health (e.g., local outdoor air quality). To overcome this problem, more recent studies have adopted such concepts as the **breathing zone**, which is defined as a zone of air around an organism from which respired air is drawn. Micro-environments include these breathing zones of difference concentrations (e.g., areas of the home, office, or car).

A second example of predictive exposure assessment is the **Monte Carlo method**, which assumes a random distribution for a given variable, and studies its influence on exposure. The name "Monte Carlo" is given to this approach because we use a random number generator instead of a single known number within the analysis. For more discussion of the Monte Carlo calculations, please see "refining the analysis" at the end of this chapter.

A third example of predictive exposure assessment is the **scenario method**. An exposure scenario is defined as a set of assumptions on exposure (including sources, exposure pathways, concentrations, and individual or population habits and characteristics). Perhaps the best known of all scenarios is the "worst case scenario," which assumes that exposure is always in the worst possible concentrations.

Figure 20 shows the differences between the three methods. Assume that air pollution has different concentrations inside four zones (zones 1, 2, 3, and 4). For convenience, we assume that the concentration of the pollutant is 1, 2, 3 and 4 ppm and that it corresponds with the number inside each ellipse. The table in figure 20 shows that the worst case scenario assumes the worst concentration (4 ppm) for every hour in an eight hour log. The micro-environment method would depend on the actual behaviors, but it is easy to imagine the numbers given in the table: if an individual lives in zone 1 and works for four hours in zone 3, we can imagine the individual starting at their home, driving to work, staying there for four hours, and driving home. The concentrations would increase depending on where that individual is at any given time in an eight hour log.

FIGURE 20. COMPARISON OF PREDICTIVE EXPOSURE METHODS



Log (8 one-hour periods)

Micro-environment	**1**	**2**	**3**	**3**	**3**	**3**	**2**	**1**
Scenario	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Monte Carlo	**3**	**1**	**2**	**4**	**2**	**3**	**1**	**1**

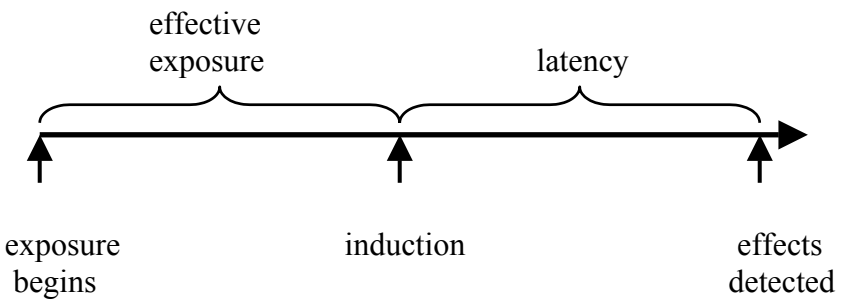
The Monte Carlo method simply shows random number generation from numbers one through four, and may not even make physical sense (initially) because it has the individual skipping

across zones (e.g. from 1 to 3) with no transition. However, it is possible to set up rules in a random number generator that overcomes this issue. Moreover, the full extent and true power of Monte Carlo simulation will be further discussed at the end of this chapter.

4B. Time of exposure

A critical variable in calculating total exposure is the time of exposure. There are several terms we need to define relative to this task. First, **induction** means "to stimulate a biological reaction." Induction falls somewhere between the start of exposure and the detection of effects, as shown in the timeline below. For example, the appearance of the first cancer cell could be called induction. Using cigarettes as an example, you can smoke and *not* get cancer *before* induction; you can have cancer and *not* yet know *after* induction. In both cases, the actual time of induction may be unknown.

Figure 21. TERMS RELATING TO TIME OF EXPOSURE



With induction now defined, we can define **latency** as the time from induction to a detected health effect. If the effects are acute, induction starts when the exposure starts (e.g., food poisoning). However, chronic effects may be different (e.g., you may be exposed to carcinogens without the occurrence of cancer).

Effective exposure is therefore defined as the exposure that leads to induction. Since the effect is inevitable once the induction occurs, the time of exposure we are interested in for our risk assessments is the effective exposure (e.g., lifetime – latency).

When does induction occur? We do not always know! These may be unknown biochemical reactions. This raises the next question: if we are not sure of when induction occurs, do we assume a large or small value of induction? It depends on the calculation, of course, but in the spirit of screening risk assessments, we always stay conservative in these calculations. The dose response models we discuss in the next chapter make different assumptions on this question.

4C. Defining dose

Dose is defined as:

the amount of a substance available for metabolic processes of an organism following exposure and absorption into an organism.

Under this definition, we see that a dosimeter (ostensibly an instrument to measure dose), often measures exposure rather than dose. Direct measurement of dose would entail measuring exposure at or near the exchange boundaries (e.g., the lungs, skin, or intestines) of an organism while exposure is occurring (no easy task!). Therefore, we must use various definitions of dose that are specific to the laboratory conditions under which they occur.

For example, **absorbed dose** is the amount of a substance penetrating across exchange boundaries of an organism, via either physical or biological processes after contact.

Administered dose is the amount of substance given to humans or animals in dose response studies, especially through ingestion or inhalation. Of course, toxicity must always take into account the route of exposure (oral, dermal, or inhalation).

Applied dose is also the amount of substance given to humans or animals in dose response studies, but is especially through dermal contact. Note that this is a measure of exposure, not dose, because it does not account for absorption. Thus, a dose response curve is often base on administered dose rather than absorbed or delivered dose.

Delivered dose is the amount of substance available for interaction with any particular organ or cell. This is generally referred to as the **target organ**, which is site of the health effect (5,6).

Dose rate is typically measured as dose per unit time (e.g., mg/day), and is often normalized to body weight (e.g., mg/kg/day). **Exposure rate** is also measured as exposure per unit time, but while the units may appear the same, it is critical to distinguish it from dose rate. **Body burden** is the total amount of a specific substance (for example, lead) in an organism, including the amount stored, the amount that is mobile, and the amount absorbed.

4D. Biokinetic Modeling

A fundamentally different way of quantifying exposure, as mentioned earlier, is called **reconstructive exposure assessment**. This approach deduces the exposure *after* absorption has occurred by using evidence within an organism. We achieve this by measuring chemical concentrations from tissues or fluids within the body.

Figure 22 lists some of the concepts that are necessary for this reconstructive approach. Collectively, they are part of **biokinetic modeling**, defined as the study of the time course of absorption, distribution, metabolism, and excretion of a foreign substance in an organism.

These models require definition of several additional terms. First, the **target organ** is the organ that is most sensitive to the chemical agent being studied. Note that it is not necessarily the organ with the *highest* concentration of the agent but is instead the one most at risk of health effects.

Second, **biotransformation** refers to the biochemical changes that can occur once a contaminant enters the body. This can include **catabolic** transformation (molecules are broken down) or **anabolic** transformation (molecules are assembled from smaller pieces). There are wide ranges of reactions that can accomplish this and are beyond the scope of this book (a biochemistry text is recommended). However, some of the most common reactions may already be familiar to the reader: oxidation, reduction, hydrolysis, and conjugation (i.e., joining atoms to produce a new compound). Another example is a **DNA adduct** that is formed when a pollutant binds with the DNA.

Finally, the **active metabolite** is the metabolic product involved in reactions *within the target organ*. Related to this is a **biomarker**, defined as any biological indicator of exposure. Biomarkers can include changes in cell turnover rates, enzyme levels, or even the early stages of disease as an indication of exposure.

Thus, reconstructive exposure assessment can measure either the concentration of the chemical in question, or its active metabolite, or the status of a biomarker (7). Ultimately, dose is redefined as the concentration of the active metabolite in the target organ.

FIGURE 22. CONCEPTS WITHIN BIOKINETIC MODELS

The following terms refer to exposure and dose.

1. exposure = concentration in the environment * duration
C(t) * time

2. intake = total amount of material taken in during an interval.
I(t) = C(t) * ROI * time (where ROI = rate of intake)
e.g., breathing is intake of air pollutants

3. uptake = total amount of material taken up by organ during an interval
U(t) = I(t) x fd (where fd=fraction deposited)
e.g., the amount taken up by the lungs and not simply expired

4. retention = fraction of material remaining in organ at time t.
R(t)
e.g., coughing. A common measure of this is the **retention half-time**, which is the time it takes to remove half of the pollutant from the organ after uptake has occurred.

5. organ burden = the amount of material in an organ at time t.
B(t)
e.g., the measured amounts actually in the target organ

6. integral organ burden = integral of B(t) over interval of time.
D
e.g., usually can be called "dose"

7. dose = a measure of primary damage occurring during a time interval.

Notes: if there are constant linear proportions between the above measures, we can use <u>any</u> of the above measures as a surrogate for dose. However, it is rare that dose is linearly proportional to these measures for all routes of exposure and all applications.

4E. Uncertainty

All of this discussion leads to issues of error, which we began in the first chapter. **Accuracy** is defined as the correctness of data (e.g., measured value - true value), and in this chapter represents the distinction between ambient exposure and actual dose. Recall that **precision** is the reproducibility of data, under given conditions. Thus, exposure studies may be quite precise, but inaccurate.

The seriousness of this inaccuracy depends on the **data quality objectives**, which is defined as the uncertainty an assessor accepts in environmental data. If, for example, the study is part of a screening risk assessment using conservative values, the data quality objectives may be satisfied if the assessment concludes there is no significant risk.

A related definition is the **limit of detection**, which is the smallest concentration detected from background levels by a given measurement process. Again, the seriousness of limits of detection depends on the data quality objectives.

A final definition is variability, which must be distinguished from uncertainty. **Variability** refers to a well-defined range of values used throughout risk analysis. One example is a gaussian plume, which varies according to a normal distribution, but is well described and can even be observed and tested. Another example is the range of values for biomarkers, which are certain to appear in a diverse population. Of course there is variability that is expected in that population. **Uncertainty** refers to the unknown aspects of that variability.

The general strategies for exposure assessment always start with real data first. If no existing data are feasible, the next question is whether the gathering of new data is feasible. If not, hypothetical data may be considered.

Often, these questions translate into making numerous telephone calls and obtaining various databases as well as field assessments of concentrations. Hypothetical data may be generated by an exposure scenario, which describes the circumstances of exposure, including various aspects of the problem, use of an agent, and so on. Such an analysis initially makes conservative assumptions, and is as explicit as possibilities about the various uncertainties. Indeed, exposure factors can be assigned distributions (8). The analysis may then focus on the multi-media aspects of exposure. Independent studies are sought out to corroborate the findings.

Quite often, the earliest part of an investigation is concerned with gathering information on the exposures that may have occurred. This is a critical time, because we may lose the opportunity for gathering important information after the initial release has occurred. As a starting point, it is useful to think in terms of the interrogatives used by news people (i.e., who, what, when, where, how, and why). For example, we may initially ask:

1. who is exposed (and who is involved in the release),

2. what is released (the characteristics of the material, its concentration, etc.),

3. when did it occur (an accurate history, especially as to its duration),

4. where did it occur (a description of the area, including the population),

5. how did it occur (i.e., how it was released, and routes of exposure), and

6. why did it occur, which is addressed in the chapter on control assessment.

We can develop these questions further by considering the many models that cover exposure assessment. In this introductory text, we cannot hope to cover all the models, but we can discuss the most common issues they raise.

As we build our assessment, the information required for most assessments include:

1. identity of the pollutant (physical, chemical, or biological form),

2. concentrations, and

3. census information in the exposure areas.

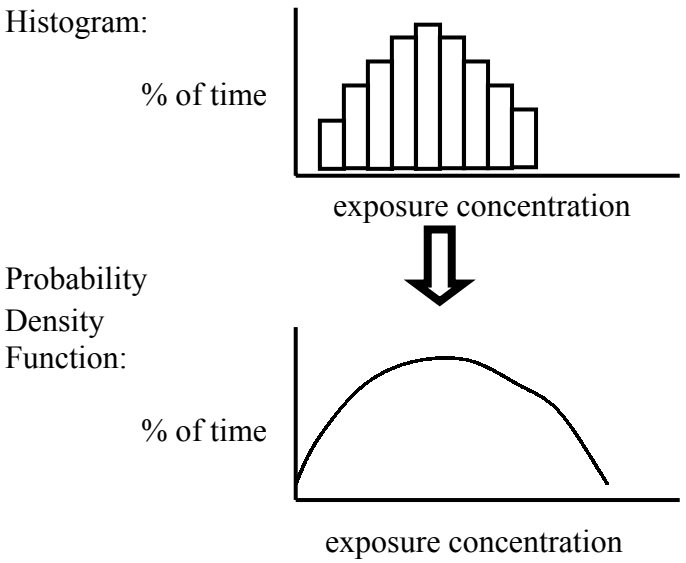
Since this information is not always available, it is critical to note when data are real and when they are assumed. Of course, uncertainties should always be noted, and we should also note the context of the exposure (e.g., production, storage, disposal). Follow-up questions should focus on concentrations and duration of exposures, and its distribution in the larger surrounding area. This approach cannot only yield reasonably accurate answers, but can help form the right questions that need to be answered for improved accuracy (9).

Refining the analysis:

For most equations in this text, we assume that each variable for a given risk has a single value. For example, the exposure concentration in a worst case scenario method is the worst single concentration for the entire life of the individual. Furthermore, the micro-environment method, though somewhat tedious, is a single concentration assigned for each given time segment.

Monte Carlo calculations take a different approach. We assume the variable has a probability density function. This function expresses the percentage of time that a variable falls within a given range. Probably the simplest way to represent this is by comparing it with a histogram, as shown below.

FIGURE 23. HISTOGRAMS AND PROBABILITY DENSITY FUNCTIONS



In the histogram, exposure concentrations are presented in intervals (e.g., 0-5 ppm, 5-10 ppm, 10-15 ppm, etc.). If these intervals becoming smaller, we could eventually connect the points at the top of each interval into a continuous curve as show in the above probability density function. The initial advantage of this approach is that it give us a much more refined view of the relative frequency for every specific concentration. However, this approach presents us with a much more powerful advantage: we can express the frequencies for any given concentration in the form of an equation, and these equations can be computerized to provide nearly instantaneous answers to a variety of questions.

Some commonly used probability distribution functions include normal, logit, probit, and Weibull. The next step is where "Monte Carlo" starts to make more sense, because we randomly sample values from this probability distribution function. We then place this sampled value into the overall calculation for exposure and obtain a predicted value. Finally, we keep repeating this process to obtain many different random samples from this probability function. Each resulting predicted value is incorporated into a probability function for the final predicted exposure. In this case, our final predicted exposure is not a single value, but actually a probability distribution of values.

Thus, in figure 20, we gave the simplest example by assuming random numbers from one to four. However, Monte Carlo simulation could assume, say, a normal distribution with a mean concentration of 2.5 and a standard deviation of 1. We could then sample from this probability distribution function at random and use each sampled number in a dose calculation. We would eventually have a probability distribution function for the resulting dose calculations.

If it all seems a bit intimidating, just remember that we need computers to complete these numerous calculations! The essence of any Monte Carlo calculation is the use of a random number generator. A Monte Carlo calculation may not bring the satisfaction of a single answer, but it refines the analysis considerably by recognizing what we already know: exposure concentrations will vary. Indeed, all the variables used throughout this text can benefit from the Monte Carlo approach. For more information on this approach, there are some excellent references provided at the end of this chapter.

It is important to remember that for many screening risk assessments, Monte Carlo calculations may simply not be necessary. A worst case scenario, for example, may conclude that the risk is not significant. If this is true by using the most conservative of assumptions, a Monte Carlo simulation will not change those conclusions.

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer.

Quiz: module 4a

1.In order to be considered as exposure, an agent must be available for absorption.

2.Predictive exposure assessment is never based on real data.

3.The microenvironment method measures an individual's immediate environment.

4.The Monte Carlo method assumes random distribution of a variable.

5.An exposure scenario always assumes the maximum exposed individual.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 4b

1.Induction refers to stimulating a biological reaction.

2.Latency refers to the time from induction to a detected health effect.

3.Effective exposure refers to the exposure that leads to induction.

4.If induction occurs at the start of exposure, the latency is 0.

5.Larger latencies lead to larger effective exposure.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 4c

1.Dose is the amount of a substance available for metabolic processes.

2.Absorbed dose is the amount penetrating across exchange boundaries of an organism.

3.Applied dose includes ingestion or inhalation.

4.Administered dose includes dermal contact.

5.Delivered dose is the amount available for interaction with a particular organ or cell.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 4d

1.Intake is the total amount of material taken in during an interval.

2.Uptake is the total amount of material taken up by organ during an interval.

3.Retention is the fraction of material remaining in organ at time t.

4.Organ burden is the amount of material in an organ at time t.

5.Integral organ burden is the integral of organ burden over an interval of time.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 4e

1.Accuracy refers to the correctness of data.

2.Data quality objectives are the uncertainty an analyst accepts in data.

3.Limit of detection is the smallest concentration detected by a given process.

4.Precision refers the reproducibility of data.

5.Data quality objectives can affect the required accuracy and precision.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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Updated online information at http://www.csun.edu/~vchsc006/469/0.html

Chapter 5: Dose-Response Assessment

Dose-response refers to a correlation between a quantified exposure (dose) and the percentage of a population that demonstrates a specific effect (response). A considerable amount of discussion has evolved around the issues of dose response assessment (1). One of the basic challenges here is that the techniques are constantly evolving. This chapter builds on the previous chapter by extending the concept of dose as a way to better understand and predict effects. As with all the previous chapters, we assume a conservative approach for each step, and examine the ways we can refine the assessment.

Terms and Concepts:

dose, response
- thresholds, extrapolation
- acute toxicity
- cancer stages
- multistage theories
- critical toxic effect

NOEL, NOAEL, LOAEL
- Safety factors
- Reference dose
- Dose scaling

Tolerance distribution models
- logit model
- probit model
- Weibull model

hit target models
- Single hit
- Multihit
- Multistage

relative potency

model free approaches
- linear model

5A. The basic equation for dose

Our basic equation for dose, which forms the basis for discussing dose response modeling, is:

$$D = \frac{C}{F} * I * \frac{70}{W} * \frac{E}{L} * T$$

where:

D = dose
C = ambient concentration (in air, water, etc.)
F = safety factors (discussed below)
I = intake (breathing, drinking, etc.)
70 = assumed weight of average human
W = weight of test animal (W = 70 for human subjects)
E = average time of exposure (usually in days)
L = average lifetime of species (usually in days)
T = time of exposure in humans

Some of these variables have already been discussed in previous chapters. For example, ambient concentrations (C) are calculated from our environmental fate modeling. Intake (I) is a concept from biokinetic modeling discussed in the previous chapter. Time of exposure (T) was also discussed in the previous chapter.

If we are dealing with data in a test animal, however, we may wish to adjust for the differences between different test animals and humans. Within this equation, we accomplish this by the quantity 70/W, commonly referred to as **dose scaling**. If we assume an average *human* body weight of 70 kg, then dividing 70 by W (the body weight of the test animal) has the effect of scaling the dose to humans.

Actually, there are many ways we could accomplish this kind of scaling: the ratio of animal to human in terms of relative calorie demand, or lifespan, or body surface area have all been use for scaling purposes. In some cases, we may even wish to adopt a statistical regression from multiple species (usually at least 4 species). However, by far the most common and simplest method is by body weight.

The variable I **(intake value**) is generally derived from standard default values. For example, figure 24 gives default intake values for different animal species. Keep in mind that these values are designed for average adults, and values can vary with age, health status, and other factors.

FIGURE 24. DEFAULT INTAKE VALUES

species	Sex	Lifespan (years)	Body weight (kg)	Food intake (g/day)	Water intake (ml/day)	Air intake (l/min)
human	M	72	75	1500	2000	7.5
	F	79	60	1500	2000	6
mouse	M	2.5	.03	3.6	5	.03
	F	2.5	.025	3.25	5	.03
rat	M	2.5	.5	20	25	.1
	F	2.5	.35	17.5	20	.1

5B. Sample problem for calculating dose

Sample problem: Using the previous assumptions, suppose a suspected carcinogen is found in water at a concentration of 0.2 mg/l. What is the average lifetime dose to a female? What are some of the underlying sources of uncertainty for these calculations?

Answers:

A number of assumptions can help simplify the original equation. For example, we might assume the following:

1. the original dose is in humans over their entire lifetime,
2. no safety factors are required
3. T = lifetime in days (i.e., 79 * 365) (assuming lifespan for females).

After these adjustments, we can calculate experimental dose with the more simplified equation:

D = C * I * T

C = 0.2 mg/l

I = 2000 ml/day = 2 l/day

T = 79 * 365 = 28835 days

D = C * I * T = 0.2 * 2 * 28835

= 11534 mg = 11.534 gm

For more guidance on the underlying uncertainties of these calculations, see “refining the assessment at the end of this chapter.

5C. Reference Dose and Other Doses for Dose-Response Assessment

Reference dose is based on the assumption of a **threshold,** which is defined as a pollutant concentration [or dose] below which there is no harmful effect. Therefore, t**hreshold dose** refers to the minimum application of a given substance required to produce an observable effect. Of course, we should be focused on the **critical toxic effect,** defined as the most sensitive and specific biological change that is outside of acceptable physiological variation.

With these initial definitions, we can add three terms that relate to this fundamental measure:

1. **NOEL**: no observed effect level. This refers to a dose in which there is no effect observed (no changes in any response). In other words, there is a suggestion that this is a safe level.

2. **NOAEL**: no observed adverse effect level . This refers to a dose in which there may be detected changes, but none deemed to be adverse.

3. **LOAEL**: Lowest observed adverse effect level. This refers to a dose in which adverse effects have been detected with statistically significant differences between the test and control groups.

Generally, the procedure is to always select the highest NOEL or NOAEL, since this stretches the limit of a dose with no effect. If no such values are available, we then select the *lowest* LOAEL. Once this decision is made, we rely on the same equation we presented in section 5a:

$$[\text{NOEL}, \text{NOAEL}, or \text{LOAEL}] = \frac{C}{F} * I * \frac{70}{W} * \frac{E}{L} * T$$

where:

C = concentration in media for a NOEL, NOAEL, or LOAEL

These values may then be used to determine the **reference dose,** defined as the daily dose with no significant risk over a lifetime. However, the reference dose must take into account the uncertainties that may be part of the NOEL and other measures. This is done by the use of **safety factors** (more recently referred to as **uncertainty factors**).

The easiest way to explain these values is by an example. Suppose we find a NOEL for chemical X in rats of 1 mg/kg/day (i.e., one milligram of chemical X per kilogram of a rat's body weight per day). We might consider using that same value for humans, but there would be doubts that what is true for rats may not be true for human. We could decide to use a safety factor of 10 in the following way:

RefD = NOEL / F = (1 mg/kg/day) / 10 = 0.1 mg/kg/day in humans.

A critical part of this equation, therefore, is the use of safety factors. These studies are not ideal and may be quite uncertain, therefore we use safety factors in the following way. Safety factors are generally set at 10 (one order of magnitude), and may be recommended for any on the following reasons:

1. intrapecies variation
2. synergism
3. less appropriate route
4. may not represent total body intake
5. matching control and experimental groups
6. matching experimental with risk group
7. latency adjustments
8. quality of the study

A dose that is critical to our analysis is the **maximum tolerated dose** (or MTD), which refers to the dose that does not lead to acute effects. We have already made mention in previous chapter about the need to avoid acute effects in a chronic bioassay – our equation for dose can now be used to translate that into appropriate experimental concentrations. This can have the effect of confounding the results.

Another frequently used measure is the **benchmark dose**, defined as the dose that induces a specific risk. For example, a benchmark dose could be developed for a 5% risk. This would require additional information on the dose response curve itself, which is discussed later in this chapter.

5D. Categories of dose response models

In risk assessment, **extrapolation** is essentially an educated guess based on observable responses and a mathematical model. The mathematical model is used to predict response levels that cannot be directly observed. All dose response models represent extrapolation.

In other words, dose response assessment must make fundamental assumptions, and these assumptions should be made explicit (2,3). For example, most approaches have been made with the assumption that the assessment does not underestimate the risk. This approach has been widely challenged, because it raises fears among those who may not fully understand the conservative nature of such an assessment. It is therefore critical to be explicit as to the nature of the assumptions.

Other assumptions must be made which may later prove false. For example, it is often assumed that the mechanism at the lowest experimental dose is the same as the dose for risk group. It is widely believed that linear dose response models are always the most conservative; however, both assumptions have proven false in certain cases.

An old approach to dose response is the **chemical kinetics model**, which generally states that the probability of response is related to the rate of chemical reactions in the body (e.g., Michaelis Menton kinetics). This approach is no longer used by most agencies. However, this approach can make up the components of other models.

The next basic category is usually called **model free approaches**, because they are not based on any supporting biological model. For example, a linear function, or even a polynomial function the fits to the existing data is a mathematical construct that is not based on any biological model of response. The problem, of course, is that this approach is sometimes difficult to defend. However, they are easy to work with, and sometimes biological considerations can be built into these mathematical constructs.

The next category of models is **threshold models** (also called tolerance distribution models). This approach is curve fitting, but with certain properties as to the shape of the curve. The fundamental basis of these models is a threshold, or a dose below which there are no effects (i.e., a safe dose).

Tolerance distribution states that tolerances will vary among a population: below one dose, no one will respond, and above the other dose, all will respond. The obvious question is: why different thresholds among the population? The answer is that humans are heterogeneous in their sensitivity to toxicants.

One example of a tolerance distribution model is the **logit model** also known as the logistic, log-odds, or log-logistic model. A logit is defined as the log of a ratio of 2 outcomes (e.g., the ratio of cases to healthy outcomes). If Pe is the percentage of cases, this can be expressed as:

logit = ln [% cases / % healthy] = ln [Pe / (1 – Pe)]

The logit dose response model states that the above logit is a linear function of the dose. If a and b help form the linear function of dose, then the normal form of the equation is:

$$Pe \equiv \frac{1}{1+e^{-(a+bD)}}$$

Other examples of tolerance distribution models are the **Probit model** ("log-normal curve") and **Weibull model.** The **Weibull model** is based on thresholds having a Weibull distribution: Pe = 1 – exp (-aD). As we shall see, the Weibull equation resembles single hit models, but is based on different assumptions. In any event, there are several inherent problems with these models. First, if D = 0, Pe does not = 0, which is biologically implausible. Second, these models have fallen out of favor for cancer models, because they do not fit well with recent data, and are recognized as among the least conservative models. Finally, there is no biological basis for selecting among logits, probits, and Weibull.

Hit target models are taken from radiation studies, where a hit is like throwing darts at a balloon. A hit may mean a chemical binding or other biochemical effect, and is assumed to be proportional to organ burden. Most of the current models are variants of hit models.

The simplest is the **single hit model**, which assumes that if a single critical target (on DNA) is destroyed by a single hit, the subject responds with cancer. The multihit model (or gamma model) assumes that if a single critical target is destroyed by k hits, the subject responds. The multistage model assumes that if a cell (with multiple targets) has undergone k heritable changes, the subject responds. Logically, the single hit model appears to be the most conservative, because a single hit is the only requirement to induce a cancer. However, there are broader considerations of what constitutes conservatism (8), as we shall consider in the next section.

5E. Response: calculating risk factors

A variety of methods may be employed to calculate risk factors. We begin with a linear approach in order to introduce some critical concepts (5). We will then consider the appropriate applications of this approach, and ways of refining the basic approach. Before we extrapolate from any of these methods, we must verify that we are examining chronic and not acute toxicity. **Acute toxicity** refers to any poisonous effect produced within a short period following exposure, usually up to 24-96 hours, resulting in biological harm and often death. Once we have verified this, we can proceed.

Recall that the risk of the test group is **Pt = Xt / Nt** where:
Pt = risk to the test group
Xt = number of cases in test group
Nt = total number in test group

Similarly, the risk to the control group is **Pc = Xc / Nc** where:
Pc = risk to the control group
Xc = number of cases in the control group
Nc = total number in the control group

Risk is operationalized as the probability of response. Sometimes it is called the "control-adjusted test group response," in reference to the conversions necessary to the test group response. There are various qualifiers, including

1. benign and malignant tumors may be counted the same
2. different target sites may be counted the same
3. individual tumor types may be counted individually or lumped together for all tumor bearing animals (depending on what leads to highest significance)

The test group must then be adjusted for the control group response. This can be done in a variety of ways. The first equation assumes that the mechanism of response is same (additive) for both test and control group. The equation simply looks at the difference between the test group and control group:

Pe = Pt – Pc

The second equation, known as Abbot's correction, assumes mechanisms of response are different (independent) for test and control group. This is the most conservative approach and is often used in risk assessments:

Pe = [Pt -Pc] / [1 - Pc].

The denominator can be thought of as the total amount of possible increase in risk. Of course, if the control group has 0 risk, the two equations are the same, and: **Pe = Pt**.

The next adjustment is to provide the upper and lower statistical limits for Pt (referred to as Pt' and Pt" respectively). This is especially important because the test group may be relatively small and part of a limited number of studies. Appendix 1 and figure 25 gives upper and lower limits for the test group response.

Pe' = [Pt' -Pc] / [1 - Pc].

Once the statistical limits for the adjusted risk are calculated, we can use these numbers to determine the risk factors for our subsequent risk assessment calculations. A linear model of dose response will be discussed further in the next chapter. At this point, however, our interest in the experimental data is to determine the risk factor (the slope) that will be applied to the risk group. The definition of R, the risk factor, is:

R = Pe / D.

In other words, R is the increase in excess risk (Pe) per dose increase. **Carcinogenic potency** refers to the slope of the dose-response curve for a carcinogen (in this case, the value of R). **Relative potency** is defined as a comparison of the potency of two or more reference chemicals. R can expedite such comparisons. If we wish to include the variables in determining dose and the upper limits used as a conservative calculation of Pe, we get:

R = Pe' / CIT

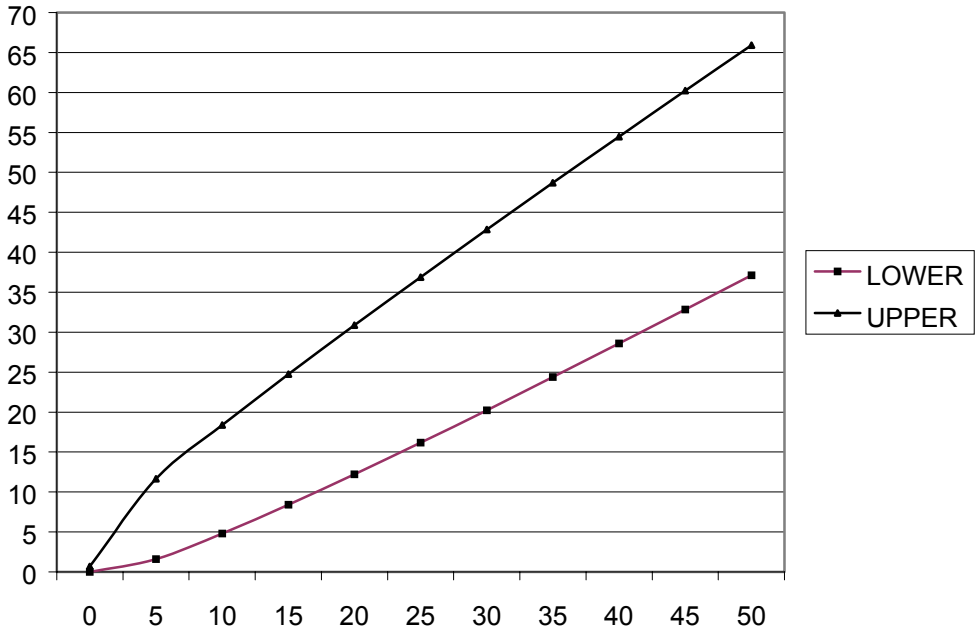
Sample problem: Suppose 20 of 200 test rats (given a dose of 1 mg), die from cancer, while 10 of 200 control rats die from cancer. Using Abbott's correction, what are the 95% upper and lower limits of the excess risk (Pe' and Pe"), and what is the unit risk factor?

Answer:
Pt' = Xt'/Nt = 30.89/200 = 0.154 (from Appendix 1)
Pt" = Xt"/Nt = 12.22/200 = 0.061 (from Appendix 1)
Pc = Xc/Nc = 10/200 = 0.050

Pe' = (P't-Pc) / (1-Pc) = (.15 -.05)/(1-.05) = .109
Pe" = (P"t-Pc) / (1-Pc) = (.06 -.05)/(1-.05) = .012

R = P'e / D = .109 / 1 mg = .11 / mg

FIGURE 25. UPPER AND LOWER 95% CONFIDENCE LIMITS OF A POISSON VARIABLE



Refining the analysis:

We can refine the analysis by considering sources of uncertainty in dose response assessment. This can help the overall analysis in at least three ways. First it can help focus research programs by identifying the largest sources of uncertainty. Second, it can help solve problems if it can clarify that the uncertainty does not affect certain conclusions of the study. Finally, uncertainty may be the key to resolving conflicts — by reducing such uncertainty, we may build consensus. For example, consider the basic equation introduced in section 5a:

$$D = \frac{C}{F} * I * \frac{70}{W} * \frac{E}{L} * T$$

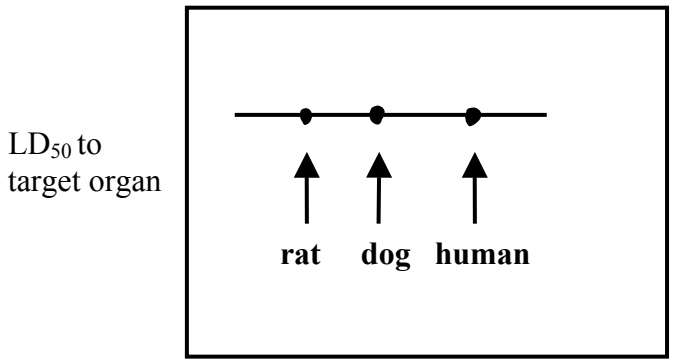
Each variable represents a source of uncertainty. As we consider additional variables, there should be a sense that our calculations are becoming more refined. Ultimately, we can refine our analysis by considering the dose to the target organ**.** For example, we could incorporate considerations of uptake, retention, organ burden, and integral organ burden. With recent advances in the understanding of biokinetics, the very definition of "dose" is evolving (4).

Given the range of uncertainty in dose calculations, it is increasingly apparent that the presentation of a single number representing dose may be misleading (1), and a number of methods have been proposed to more accurately characterize the dose (6,7). By analyzing these uncertainties, we can develop a more refined estimate of the risk. A primary example of this is age. While counter-examples can exist, here are just a few examples of the influence of age:

1. uptake tends to decrease with age;
2. retention tends to increase with age;
3. various intake rates change in both directions;
4. gastrointestinal absorption rates tend to be higher in neonates;
5. rates of mitosis tend to be higher in children
   (this tends to magnify the effect of initiation and promotion in carcinogenesis);
6. risk factors change with age, children being generally more sensitive;
7. breathing patterns tend to be faster with infants;
8. retention function can vary by at least an order of magnitude among individuals;
9. ingestion rates certainly vary from infants to adults;
10. blood absorption can be two orders of magnitude higher in first 6 months of life;
11. children have smaller organ mass, and generally less cells.

Ultimately, by accounting for these sources of uncertainty, we can develop a more consistent picture of toxicity among different species. For example, consider figure 26. If the LD_{50} for different species forms a consistent pattern (e.g., a straight line), we can be much more confident that the predictions for humans are accurate.

FIGURE 26. TARGET ORGANS CAN IMPROVE EXTRAPOLATION



Finally, we can refine a dose-response assessment by selecting a non-linear model such as logit or single hit models. Such approaches are best accomplished by computer applications of non-linear regression that approximate the various non-linear dose-response equations. Nevertheless, our ability to accurately identify the dose to the target organ can substantially refine our risk estimates and clarify our choices among the non-linear alternatives.

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 5a

1.If a safe concentration is 1 mg/l with intake of 2 l/day, then the daily dose is 2 mg.

2.If a safety factor of 10 is applied to the previous dose, then the reference dose is 20 mg.

3.For a lifetime of 79 years in a maximum exposed individual, the safe lifetime dose is
20 * 79 * 365

4.If time of exposure is 7.5 years, then the lifetime dose is a tenth of the previous calculation.

5.If time of exposure is 7.5 years, then the reference dose is a tenth of the previous calculation.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 5b

1.Uptake tends to decrease with age.

2.Retention tends to increase with age.

3.Various intake rates change in both directions.

4.Gastrointestinal absorption rates tend to be higher in neonates.

5.Rates of mitosis tend to be higher in children.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 5c

1.An experimental dose is generally higher than the dose of the risk group.

2.Reference dose is the daily dose with no significant risk over lifetime.

3.NOEL is the highest measured level in which there is no effect.

4.A NOAEL ignores benign effects.

5.LOAEL is the lowest measured level in which adverse effects are observed.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 5d

1.The probability of response is directly proportional to the rate of chemical reactions in the body.

2."Model free approaches" are not based on any supporting biological model.

3.Threshold models are also called tolerance distribution models.

4.One example of a tolerance distribution model is the logit model.

5.The simplest of the hit models is the single hit model.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 5e

1.Abbot's correction says that risk is (Pt-Pc) / (1-Pc)

2.If Pc is large, then Abbot's correction has a greater influence.

3.If Pc is 0, there is no need to report Abbot's correction.

4.If the lower limit of Abbot's correction is less than 0, there is no statistically significant difference between test and control group.

5.If the population is large, then the upper limit will always approach the lower limit.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Dose Response Assessment: bibliography

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For more information:

Low-Dose Extrapolation of Cancer Risks: Issues and Perspectives (Olin S, Farland W, Park C, Rhomberg L, Scheuplein R, Starr T, Wilson J, eds). Washington: ILSI Press, 185-198, 1995.

Updated online information at http://www.csun.edu/~vchsc006/469/0.html

Chapter 6: Risk Characterization

Risk Characterization is the final step of a risk assessment, where we integrate information from the previous steps to produce the above measures. A simple but effective orientation to this approach is to consider the interrogatives of "who, what, when, where, and why" of the given risks (1). Throughout this section, we will consider the uncertainties of our assessment, which can be especially challenging with weak carcinogens (2). Nevertheless, effective use of data can guide the expression of our uncertainties (3), and an appropriate format can allow for ongoing refinement and reduction of those uncertainties (4). This chapter shows procedures for calculating excess risk, excess number of cases, and risk-based acceptable standards. It considers uncertainty analysis as part of these calculations and works through a number of sample problems in order to illustrate these procedures. The reader is encouraged to follow up with some of the outstanding references at the end of this chapter.

Terms and Concepts:

Calculations
- Individual excess risk, Pe
- Excess cases, E.C.
- Risk factor, R
- Acceptable concentration, A.C.

Uncertainty
- Experimental range
- Sub-experimental range
- Plausibility analysis
- cumulative distribution functions
- uncertainty analysis

TOXNET, IRIS
risk report formats

6A: Individual excess risk, Pe

In the **experimental range** (i.e., where the curve is supported by actual experimental data), the excess risk (Pe) is determined simply by reading off the dose response curve. For example, consider graph 1 of figure 27. At a dose of "B", we can simply read off the curve for a response rate of "x." In the sub-experimental range (e.g., a dose of "A"), it is unclear what the response rate should be. The simplest approach is to draw a straight line from the origin to the lowest experimental data point. For example, graph 2 of figure 27 inserts a straight line from the lowest data point to the origin. The meaning of this straight line can be summarized by the familiar linear equation:

y = mx + b where
y = risk (response),
x = dose, and
m = "risk factor"
b= y intercept (when x=0),

"b" could be thought of as the background risk, but "y" is almost always expressed as the "excess" risk, so that background risk is not normally part of the measure. The x intercept (i.e., when y=0) is -(b/m), and could be thought of as the threshold (e.g., NOEL). However, we normally assume b=0, (i.e., no threshold), so b usually has no practical meaning and is dropped from the equation. Therefore, translating this into the symbols normally used in risk assessment, y=mx becomes:

Pe = R D = R C I T, where:

Pe = individual excess risk (response)
R = risk factor (the slope of line, and the excess risk per unit of dose)
D = individual dose = C I T

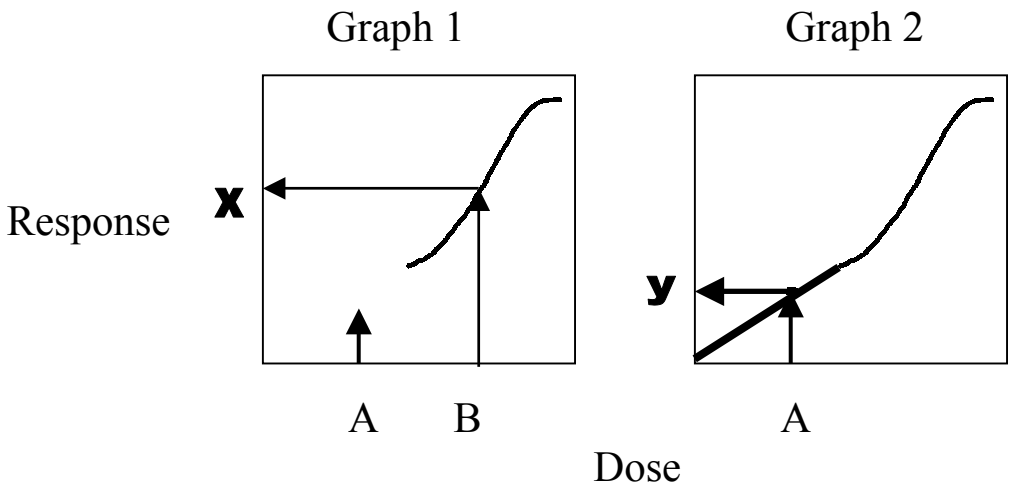
Furthermore, by isolating R algebraically, we have: R = Pe / D, where:
Pe = the excess risk in an exposed population, and
D = the dose where this risk occurred

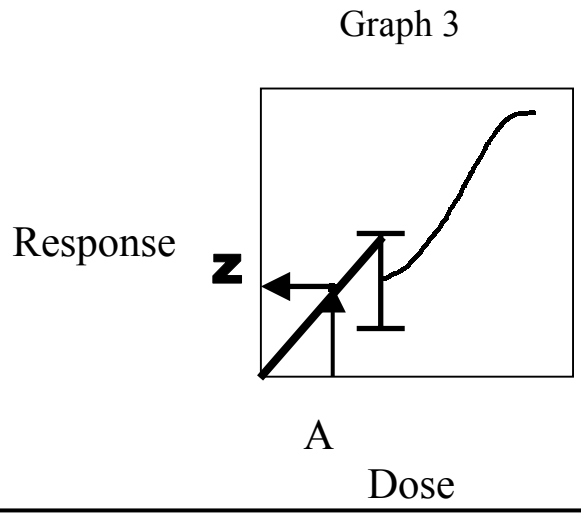
A popular belief is that the linear dose response is the most conservative model, but there are various fallacies in this belief:

1. it assumes same mechanism of toxicity at low doses
2. it assumes experimental group data applies to the risk group

If the true dose response curve is supralinear, for example, then this assumption does not hold up. Therefore, the traditional approach is to use the statistical upper limit of P. This is represented by graph 3 on figure 27, which takes the upper and lower statistical limits of the LOAEL, and draws a line from the upper limit (Pe') to the origin.

FIGURE 27. EXTRAPOLATION OF A DOSE RESPONSE CURVE





6B. Excess cases

Excess cases refer to the expected or average loss over a large number of trials. It represents a statistical average, and we need to be cautious about using this value in cases for which there will be only one, or a few, trials. Nevertheless, it is a frequently reported value, and the calculations are relatively straight-forward.

In the **experimental dose range**, **EC = P N**, where:

EC = excess cases
N = population at risk
P = risk read off the curve

In the **sub-experimental dose range**, the approach is again to draw a straight line from an experimental data point to the origin:

EC = P N = R D N = R C I T N

There are variables that can interfere with this approach, especially the age distribution of the population. For example, older individuals may not live throughout the projected latency, and life expectancy gets longer as individuals get older. Still, this usually affects a small percentage of population, and the other uncertainties within the assessment are usually a greater influence on the risk calculations. Other problems with this equation are that there are changes in the exposure (concentrations, time of exposure), and the population itself over time.

The way to overcome these issues within a screening risk assessment is to report the *upper limit* of the excess cases, which requires the upper limit of Pe in our calculations. Of course, this actual reporting of numbers of deaths will raise issues in the risk communication and risk management phases, and depending on our needs we may adopt more refined ways of handling these issues. The issue of uncertainty is further addressed in the next section.

6C. Uncertainty analysis

Uncertainty analysis refers to a detailed examination of the systematic and random errors of a measurement or estimate. It is an analytical process to provide information regarding the uncertainty. As we have emphasized throughout this text, all risk assessments have uncertainty. It is the responsibility of the analyst to be clear about the uncertainties of the analysis, the assumptions that have been made relative to these uncertainties, and the range of confidence in the characterization of any risk.

There are a number of techniques for accomplishing this. For example, the previous chapter showed how to calculate not only the statistical upper limit but also the statistical lower limit for the risk factors. In a screening risk assessment, we have the natural tendency to use the statistical upper limit; however, the statistical lower limit can also be used in risk characterization, which in turn can give upper and lower limits for the excess risk, Pe, for the excess cases, EC, and even for the acceptable concentrations, AC, calculated in the later sections of this chapter.

Furthermore, if we look for trends of greater or lesser risk per dose from different data points to the origin, we can surmise whether the curve is consistent as it approaches the LOAEL. While a simple approach would take a visual approach, a more sophisticated approach could rely on multiple regression (e.g., trend or time series analysis).

Other possibilities for checking trends include **plausibility analysis**, which compares the assessed risk with overall national rates. This approach can be reasonable, because a higher assessed risk should be detected by epidemiological studies. However, these results may be inconclusive.

The good news is that uncertainty analysis along with most of the necessary data can be found on databases on the Internet. Most notably, a critical part of **TOXNET** (the toxicology database network) contains the **IRIS** database (integrated risk information system), which contains the unit risk factors for hundreds of agents. Along with these values are extensive uncertainty analyses. TOXNET and IRIS were discussed earlier in chapter 2, and greater detail is provided in Appendix 3.

Finally, in “refining the analysis” at the end of this chapter, we discuss cumulative probability distributions as a more refined way of expressing uncertainty.

6D. Acceptable Concentration Using Safety Factors

Sample problem: A neurotoxin has a NOEL of .05 gm/day in male rats. The EPA Science Advisory Board recommends an uncertainty factor of 10. What is the reference dose for humans?

Answer:

$$\text{reference dose} = \frac{.05 \text{ gm/day} * 70 \text{ kg}}{.5 \text{ kg} * 10} = .7 \text{ gm/day}$$

Notes:

1. For dose scaling purposes, assume humans weigh 70 kg and the male rats weigh .5 kg.
2. With no other information, we assume no latency and a lifetime of exposure and study (the simplest conditions).
3. Remember that reference dose is a daily dose.
   Doses should always be expressed as a daily dose.
4. Pay close attention to the units at all times!

6E. Sample problem for a carcinogen

Sample problem: With the information given below, try to solve the problems on your own. The answers are given on the next page.

1. Assume the following:
   C = ambient concentration of 1 mg/m3
   I = daily inhalation intake of
   20 cubic meters per day (20 m3/day)
   T = lifetime exposure of 28,470 days
   (78 years x 365 days = 28,470 days)

2. What is the daily dose and lifetime dose?

3. Assume that the adjusted value of P is 0.1 for a test animal population given a lifetime dose of 10 kg. What is the unit risk factor?

4. What is the lifetime risk to the risk group in this study?

5. What are the excess cases expected for a town of 100,000 people exposed to this chemical?

6. What is the acceptable concentration for this chemical (assume that one in a million risk is an acceptable risk).

Answers:

1. Note: these are assumptions, and the answers could change depending on the assumptions we make.

2. What is the daily dose and lifetime dose?

D = CIT = (1 mg/m3)(20 m3/day)(1 day) = 20 mg/day

D = CIT = (20 mg/day)(28,470 days) = 569,400 mg
= .5694 kg/lifetime

3. Assume that the adjusted value of P is 0.1 for a test animal population given a lifetime dose of 10 kg. What is the unit risk factor?

R = P/D = (0.1)/10 kg = .01/kg

4. What is the lifetime risk to the risk group in this study?

P = RD = (.01/kg)(.5694 kg) = .005694

5. What are the excess cases expected for a town of 100,000 people exposed to this chemical?

EC = PN = (.005694)(100,000) = 569.4 deaths over a lifetime of exposure

6. What is the acceptable concentration for this chemical (assume that one in a million risk is an acceptable risk)?

AC = E-6/RIT = E-6/(.01/kg)(20 m3/day)(28,470 days)

= E-6/5,694 = 1.7562 x e-10 kg/m3 = .17562 microgram/m3

Note: this approach could also be applied to determining the benchmark dose. By assigning a benchmark of, say 5%, we could deduce the dose that would lead to such a risk. Obviously, such a dose would not be an acceptable dose (given the high risk), but it can be a more accurate benchmark for comparing different chemical agents.

Sample problem: A suspected carcinogen appears in L.A. water at an estimated concentration of 0.2 mg/l.

1. What assumptions must you make in estimating dose?

2. What is the daily dose to a 60 kilogram female adult with average water intake?

3. What is the average lifetime dose (D) for this individual?

4. In toxicological tests with this chemical, 20 of 200 rats die from cancer. In the control group, 10 of 200 rats die from cancer. Is this difference statistically significant?

5. Using Abbot's correction, what are the Poisson upper and lower limits (95% confidence) of the excess risk (Pe' and Pe")?

6. The excess risk given above is at a dose of 110 gm in rats. What is the unit risk factor (R) for this chemical?

7. At the human dose calculated in question #3 (a much lower dose), what is the excess risk (P) for this exposure?

8. What is the excess number of cancer cases (E.C.) if 10 million people in greater Los Angeles (not the entire population) are exposed to this pesticide in the drinking water?

Answers:

1. C: all water supplies have the same concentration, no other sources of exposure
   I: intake is a default value and only through ingestion
   T: lifetime exposure (worst case)
   F: no safety factors
   W: no dose scaling
   L: no latency
   assume that the agent causes cancer!

2. D = C/F * I * 70/W * E/L * T
   = C * I * T
   C = 0.2 mg/l
   I = 2.5 l/day
   T = 78 * 365 = 28,470 days

   daily C * I = 0.2 mg/l * 2.5 l/day
   dose = 0.5 mg/day

3. life C * I * T = 0.2 * 2.5 * 28,470
   dose = 14.2 gm

4. test: Xt = 20 Nt = 200 Pt = 0.1
   control: Xc = 10 Nc = 200 Pc = 0.05
   p = 0.075 q = 0.925
   Nt p = 15 > 5
   Nt q = 185 > 5
   Nc p = 15 > 5
   Nc q = 185 > 5 (assume normality)
   z = 1.90, therefore p = .029
   yes, statistically significant @ 95% confidence.

5. Pc = 0.05
   P't = 30.89 / 200 = 0.15445 (using Appendix 1)
   P"t = 12.22 / 200 = 0.0611 (using Appendix 1)
   P'e = (P't - Pc) / (1 - Pc) = 0.109947 = **.11** (rounded)
   P"e = (P"t - Pc) / (1 - Pc) = 0.011684 = **.01** (rounded)

6. R = P'e / D = .11 / 1.10 E+05 mg
   = 1 E-06 / mg

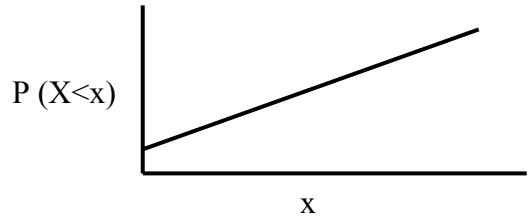
7. P = R * D = (1 E-06 / mg) * 1.42 E+04 mg
   = 0.0142

8. EC = P * N = 0.0142 * 1 E+07
   = 142,000

Refining the analysis:

A variety of methods have been proposed for refining the expression of uncertainty in risk characterization (5-7). Furthermore, there are techniques for evaluating uncertainties in site-specific risk assessments (8). As mentioned in section 2E, a classification system is a useful starting point for integrating different forms of information on hazards, but there are opportunities to improve on this thinking. Any description of potential hazards must consider the uncertainty of the data and the environmental circumstances that are relevant to the hazard (7). Instead of addressing degrees of uncertainty with discrete classifications (e.g., the EPA approach to carcinogens), many have recommended the use of a **cumulative probability distribution function** to indicate more precisely the degree to which experts feel a hazard may reach a certain risk. For example, consider the following figure.

FIGURE 28. CUMULATIVE PROBABILITY DISTRIBUTION



where: x = an assumed value
X= actual risk

P(X<x) is the probability that the actual risk X is less than an assumed value x. For example, in the above figure, the scientist indicates there is a small probability that the actual risk is 0. As x increases, there is an increasing probability that the actual risk is lower than x. From the standpoint of calculus, the cumulative probability function is the integral of the probability distribution that was discussed at the end of chapter 4. This approach is more quantitative and systematic in presenting the scientist's perception that the risk is less than a given number. Because we provide a graph, there is a more comprehensive presentation about the hazard.

This approach has its advantages and disadvantages. The American Industrial Hygiene Association has taken the position that single point estimates with no characterization of uncertainty are unacceptable (9)**.** Clearly, the above approach goes well beyond a single point estimate. On the other hand, this approach is conceptually much more challenging, particularly to an untrained audience. A simpler alternative to achieve this goal would be to report a statistical upper limit and lower limit (along with an expected value).

From the standpoint of reporting formats, a hypothetical outline of a "refined risk analysis" is presented below with asterisks next to potentially optional items. While formats inevitably

depend on the sponsoring organization, this particular format was adapted from recommendations originally given by the California Air Pollution Control Officers Association. It is intended here to give a clearer idea of how reports can be progressively refined.

Refined Risk Assessment

I. Executive Summary
A. facility description
B. key exposures
1. substances emitted
* 2. MEI
* 3. sensitive receptors
* 4. isopleths
C. summary of risks (cancer, non-cancer)

II. Risk Assessment
A. hazard identification (cancer, non-cancer)
B. exposure assessment
1. Q, C (PTPLU, etc.)
* 2. define zones of impact: areas of elevated C
* 3. census information and sensitive receptors
* 4. other exposure pathways
C. dose response assessment (R)
D. risk characterization
1. key exposures:
PMI
* sensitive receptors
* isopleths
2. P (risk at PMI)
3. E.C. (excess cases)
* 4. A.C. (acceptable concentrations)
5. Uncertainty analysis
upper and lower limits
compare to existing standards

* III. Conclusions
* IV. Risk Management Options
V. Appendix
1. calculations
2. printouts
3. references

* = may be optional in a screening risk assessment

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 6a

1.Risk is equal to dose times the risk factor (P=RD).

2.Acceptable dose is equal to acceptable risk divided by the risk factor (D=P/R).

3.Risk is equal to the risk factor multiplied by concentration, intake, and time (P=RCIT).

4.Acceptable time of exposure is acceptable risk divided by the risk factor times concentration and intake (T=P/RCI).

5.Acceptable intake is equal to acceptable risk divided by the risk factor times concentration and time of exposure (I=P/RCT).

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 6b

1.All of the next 5 questions refer to a population of 10,000.
If the risk is .001, then there are 10 excess cases.

2.If dose is 1 gm and the risk factor is .001/gm, then there are 10 excess cases.

3.If concentration is .5 gm/l, intake is 2 l/day, and duration is 1 day, then there are 10 excess cases.

4.If the population is doubled and all other variables stay the same, then excess cases are doubled.

5.If dose is cut in half and all other variables stay the same, then excess cases are cut in half.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 6c

1.If the adjusted risk to the experimental group is 0.01 at a lifetime dose of 1 kg, then the risk factor is 0.01/kg

2.If the risk factor is .0001/gm and the lifetime dose is 1 gm, then the risk is 0.0001.

3.If the risk factor is .0001/kg and the lifetime dose is 1 gm, then the risk is 0.0000001.

4.If the risk factor is .0001/gm and the lifetime dose is 1 kg, then the risk is 0.1.

5.If the risk factor decreases with a lower LOAEL, then we could be overestimating the risk factor.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 6d

1.If P is an acceptable risk, then the acceptable dose is P / R

2.If P is an acceptable risk, then the acceptable concentration is P / RIT

3.If D is the LOAEL, then the acceptable concentration is P / RIT

4.The risk of a NOEL (especially after safety factors) is 0.

5.The risk of an acceptable concentration is less than the risk of a LOAEL.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 6e

1. If P is .0475, then the acceptable dose is P / R

2.If P is an .093, then the acceptable concentration is P / RIT

3. If D is the NOEL, then the acceptable concentration is P / RIT

4.The risk of a LOAEL (especially after safety factors) is 0.

5.The risk of an acceptable concentration is less than the risk of a NOEL.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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Chapter 7: Risk perceptions

In the previous chapters, it is easy to forget that risk assessments may be prompted by the risk perceptions of an issue. For example, fears may have been the real underlying reason for the original assessment. Thus, an examination of risk perceptions can quickly demonstrate the gap between assessed risks and the risks as they are viewed by different stakeholders (1). It is especially important, however, to recognize that all humans are prone to these risk perceptions. The psychological dimensions of risk have been characterized as "outrage factors" (2), which have been divided into two sections within this chapter. A knowledge of these perceptions along with risk assessments is the basis for formulating effective risk communication strategies (3,4).

Terms and Concepts:

biases
- overconfidence
- conjunction fallacy
- hindsight bias
- de minimus

heuristics
- representativeness
- availability
- anchoring
- framing

Outrage Factors

Risk Comparisons

7A. Common biases in risk judgments

Bias refers to a prejudice or inclination towards a particular conclusion. Long associated with various social ills (e.g., racial bias or gender bias), bias can also have a much broader meaning. Over the course of a given day, for example, think about the judgments you must make without the benefit of the scientific method: where you go, who you see, how you travel, and what you do are just a few examples that may require judgments without complete information.

Taken in this broader context, all humans have biases. These biases have a powerful influence over risk perceptions, and we ignore them at our peril! Psychologists have long studied these biases, and I summarize some of them in this discussion.

1. Ignoring assumptions

As we know by now, all risk assessments require assumptions. If these assumptions are forgotten or simply treated as facts, this can influence our perceptions of risk. For example, the original Rasmussen risk assessments of nuclear power assumed, among other things, that there would be no nuclear waste. It eventually concluded that nuclear power was safe.

Of course, we all know that there is nuclear waste. Rasmussen was explicit in this assumption, as all good risk assessors should be. The problem was not within the studies themselves – most regard them as brilliant. The problem was that the Rasmussen studies were so widely cited that many people forgot the original assumptions. On the other hand, when we make extremely conservative assumptions in a risk assessment, these too can be forgotten by the time the results reach the public.

2. Ignoring uncertainty

In the 1960's, Senator Edmund Muskie jokingly announced that he was in search of a "one-armed scientist." He explained that he was tired of scientific conclusions ending with "but on the other hand…"

All of this reflects such a strong desire for certainty that we are tempted to ignore uncertainties. This, of course, is bias. Indeed, some people may see reports of uncertainty as a cover-up or personal weakness, which can sometimes happen in the media. Unfortunately, the truth is usually more than just a sound bite.

3. Ignoring tradeoffs between risk and money

It is distasteful to put a price on human life, so we tend to ignore these tradeoffs. However, tradeoffs are exactly what we do every time we decide how to fund our health and safety programs. If we can assess the risks of death and the costs of programs, it follows that we can assess a price for human life.

Of course, life is priceless. However, consider the extremes: if a program cost $5 to save a human life, we would all support funding for such a program. If another program cost $5,000,000,000 to save a single human life, we might agree that this money could be put to better use (for example, in other programs that would save many more lives).

4. Ignoring small numbers

Consider 1 driving death in 50 million miles (or 50,000,000 miles per death). Surveys show that most people consider this an insignificant risk. However, 50 years of driving at an average of 10,000 miles/year equals 500,000 miles per lifetime. Using these new numbers:

[500,000 miles per lifetime/50,000,000 miles per death] = 0.01 deaths per driving lifetime. Faced with a 0.01 risk, most people consider this more significant than 1 death/50,000,000 miles. Yet, under these reasonable conditions, they are the same!

Both numbers are accurate, but the lesson is simple: when it comes to risks, we ignore small numbers. To capture people's attention, we should choose units that result in bigger numbers. For example, we could report the risk of death per ton of pollutant released, or the risk of death per million dollars of corporate profit. Not surprisingly, this is a common tactic among activists.

5. Hindsight bias

Another dangerous assumption is that the past always predicts the future. In other words, "it won't happen to me in the future, because it hasn't happened to me in the past." The power of this assumption was found in a survey in 1981 that found that 90% of all drivers believe they are better than average!

As the old saying goes, "hindsight is 20/20." However, risk assessment is always looking into the future. Soon after Len Bias was drafted by the Boston Celtics, he was found dead of a cocaine overdose. On the same day of his death, every person interviewed on the street (many who admitted to using cocaine) insisted that a cocaine overdose would never happen to him or her.

6. Context bias

Nuclear power was introduced to the world as a bomb. That context can never be too far from the perceptions that we have about nuclear power. However, if petroleum had been introduced to the world as napalm, it would be much harder to cruise down the road knowing you had 10 gallons of it underneath you. Sadly, this context is lost, even in some very recent news events.

7. Conjunction fallacy

Adding details to a risk makes it less probable, because there are more restrictions. However, adding details may also make it seem more plausible. Consider these two examples:

1. Sometime during class lecture, I predict that a man will walk into our classroom.

2. At 7:15, Dr. John Smith will walk into our classroom for a guest lecture.

By definition, example #2 is a more specific case of #1 and is therefore less plausible: instead of "sometime during class," we require that it be 7:15; instead of "a man" walking into the classroom, we require that it be Dr. John Smith, and for that matter that he give a guest lecture.

Although the second example is more restricted, it may seem more likely because of the richness of detail. Thus, as we add more specific conditions to a risk assessment, we can have the paradox of the assessed risk going down while the perceptions go up.

7b. Heuristics

A heuristic can be thought of as an informal rule used to simplify decisions. Based on research that started with Amos Tversky and Daniel Kahneman, heuristics are a natural and necessary part of being human: we face complex decisions virtually every day; these informal rules help us to simplify and therefore cope with such decisions. Unfortunately, these heuristics can also lead to faulty judgments. This is best explained by defining a specific heuristic and giving some examples.

1. **Representativeness** refers to the similarity of new events to known processes (and thought to be representative). This informal rule can help simplify decisions, because known processes can help us evaluate new processes. Unfortunately, it can also lead to errors. Consider the following example:

   Steve works in a library. Steve is shy, he reads lots of books, he seems to know a great deal about libraries, and he wears thick glasses. For some, representativeness might suggest that Steve is a librarian. However, Steve could be a janitor, a student assistant, or perhaps a security guard.

   The underlying fallacy of representativeness is that we use very small samples or anecdotal evidence to generalize about a population. For example, if a small cancer cluster is found in a large community, some may conclude that carcinogens must be present in the community. However, the only way to verify this is to test for statistical significance. In particular, statistical power (type two error) can be useful in preventing representativeness from leading to faulty judgments.

2. **Availability** refers to the ease of imagining or recalling an event. The more easily we recall an event, the more we raise our risk estimates for a particular event. For much of human history, it makes sense that higher risk would lead to increased recall. However, with the advent of television and movies, we can recall events that have little to do with the underlying risk. For example, after the movie "Jaws" was released (the Steven Spielberg movie about a man-eating great white shark), more people were afraid to swim in the ocean, even in areas that had never seen great white sharks! People who stayed out of the water had a greater risk from skin cancer than from a shark attack.

   Personal experiences can also affect availability: a single car accident, if it happens to you, can raise your estimate of the risk from driving.

   Numerous examples of availability can be found. For example, in the U.S., cars kill more people than handguns. Diabetes and breast cancer kill twice as many people each year than fire and homicides. Yet, the public routinely over-estimates the risks from handguns, fires, and homicides. These events are more likely to be reported in the news.

The conclusion here is that our recollections are an incomplete history. Risk assessments help test those recollections in a more systematic and rigorous manner.

3. **Anchoring** refers to the fact that we tend to stabilize (or anchor) our probability estimates towards our first numerical estimate. Our initial risk estimates are a reference point used to improve the consistency of subsequent responses, but if the reference point (our initial risk estimate) is inaccurate, this can lead to bias.

   In one experiment, subjects were given a list of nations and asked if their population was greater than or less than x. However, in the first group, x was equal to 5 million; in the second group, x was equal to 50 million. For the second group. the average population estimates for all nations were roughly 10 times higher than the second group!

   The conclusion here is that the first estimate has a powerful influence on subsequent estimates, so we should always be careful about reporting early results.

4. **Framing** refers to the fact that our risk estimates depend on whether the risk is expressed (or framed) as a gain or a loss. Consider the following example -- a plane carrying 100 passengers crashes, and you are asked which option you prefer:

   A. 50 people will die; or

   B. 50% chance that 90 people will die, and
      50% chance that 0 people will die.

   Before you read on, you can participate in this experiment by circling the option you prefer: A or B.

A second group was asked to make the following choice:

A. 50 people will survive; or

B. 50% chance that 10 people will survive, and
50% chance that 100 people will survive.

No fair peaking! After you've made your choice, you may notice that the only difference is that the risks are framed either as a loss (deaths) or gain (survivors). Most people are risk averse to gain and risk prone to loss. In other words, most people prefer the 50/50 chance when deaths are expressed, because it is difficult to accept a certainty of 50 deaths. However, most people prefer 50 people surviving, because it appears as a positive outcome.

One of the provocative conclusions we may draw from this is that the rich may view risks differently than the poor, because the same event may be viewed as a loss by some and as a gain by others.

7c. Outrage Factors (part 1)

One of the biggest breakthroughs in risk communication occurred when psychologists identified the major elements that raise outrage. These elements are among the most powerful contributors to the anger and frustration that are often associated with controversial risk issues.

The original research centered on situations where individual perceptions depart from assessed risks. What are the psychological factors that influence this phenomenon? What we now know is that a relatively small number of factors, often referred to as "outrage factors", are the best predictor of this phenomenon. To put it more simply, when individuals are outraged, they tend to over-estimate risks; when they are not outraged, they tend to under-estimate risks. These factors are listed in the figure below.

FIGURE 29. OUTRAGE FACTORS

More outrage	Less outrage
1. coerced	voluntary
2. industrial	natural
3. exotic	familiar
4. memorable	not memorable
5. dreaded	not dreaded
6. catastrophic	chronic
7. unknowable	knowable
8. outside control	individual control
9. unfair	fair
10. immoral	moral
11. suspicious source	trusted source
12. unresponsive process	responsive process
13. vulnerable populations	Average populations
14. delayed effects	immediate effects
15. affects future generations	does not affect future generations
16. identifiable victims	Statistical victims
17. not preventable	preventable
18. few benefits	many benefits
19. media attention	no media attention
20. opportunity for collective action	no opportunity for collective action

This knowledge can be useful to risk communication for at least two reasons: 1) they can help us to anticipate problems by evaluating whether outrage factors are relevant for a given risk analysis; and 2) they can lead to strategies to more effective risk communication. We discuss both for each of the following outrage factors.

coerced vs. voluntary risks. We have known for some time now that individuals are far more willing to assume risks if they are voluntary than if they are coerced. Think of this simple example: suppose you were forced (without any prior knowledge or preparation) to attach two long, slippery boards to the bottom of your boots, and then you were pushed off the top of a snowy mountain, slipping and sliding the entire way. If you did not know any better, you might call that cruel and unusual punishment! Most of us, however, will recognize this activity as the sport of skiing. Of course, if a beginning skier were forced down an advanced mountain slope, it is easy to see this as an outrageous event. The difference between punishment and sport is often a matter of attitude. Specifically, it makes a huge difference whether it is a voluntary activity or a coerced activity. The same issue can be found in sky-diving, mountain climbing, stunt-piloting, and marathoning!

The conclusion here is that we can reduce outrage by making it a voluntary activity. In other words, the right to say "no" to an activity raises the probability of saying "maybe" to that activity. When citizens are early participants in an issue and are given genuine participation, outrage may be reduced.

industrial vs. natural risk. Industrial risk tends to raise more outrage than natural risks. It seems that whenever there is increased human involvement, there is likely to be greater outrage. For example, humans have more influence over industrial designs than, say, the frequency of lightning or earthquakes. While natural risks can cause a great deal of damage, it is more difficult to develop outrage towards what is a natural process.

Here's another simple example: suppose XYZ Company compares the risks from their activities with the risk of being struck by lightning. Since natural risks are sometimes referred to as "an act of God," some individuals may subconsciously think "that company is comparing themselves to God." From there, it is not hard to see why many individuals would be outraged by such comparisons. The conclusion here is a simple one: avoid making comparisons between industrial and natural risks. While it may be tempting to put a complex risk into an easily understood context, these type of comparisons tend to raise more trouble, confusion, and outrage.

The conclusion here is that we should avoid comparing industrial risks to natural risks. It may be perceived as a tactic to avoid blame, and may simply add to the outrage (i.e., humans cannot usually be blamed for an act of nature, whereas they CAN be blamed for negligence in an industry)

exotic vs. familiar. Most people are not surprised to hear that exotic risks raise more outrage than familiar risks. However, this insight may help to explain the apathy we often see regarding exposures to radon. Where is the chief concern for radon exposure? In the home! The home is one of the most familiar and comfortable settings for anyone. Similarly, hazardous wastes tend

to be a high concern for many individuals, but that concern tends to diminish when we consider household hazardous wastes.

As we consider these examples, it is easy to think of counter-examples, often because other outrage factors are at work. Remember, however, that these outrage factors, taken in combination, do an effective job in understanding how outrage develops. If familiar risks tend to lower outrage, the strategy here should be clear: the more we educate people on risks, the more familiar they become. When such risks no long seem so exotic, there tends to be less outrage. Unfortunately, some organizations may be reluctant to offer educational programs for fear of stirring up outrage. While this may be true in the short term, we can see that in the long term this education should pay dividends.

memorable vs. not memorable. Memorable risks raise more outrage. For example, events that are reported in the news, events that may be part of your personal history, and even the movies may make certain events more memorable. For example, after the movie "Jaws" was first released, false reports of shark attacks increased dramatically and countless citizens were afraid to go into the water. Beaches that had never seen a great white shark were having to respond to concerned citizens! Of course, part of this was a tribute to a movie's memorable scenes of a shark attack. As another example, the Exxon Valdez will be long remembered as the oil supertanker to have a huge spill off Prince William Sound in Alaska. Once you have that thought in your head, it is difficult to get rid of the association.

So, what can we do to deal with memorable risks? The key is to acknowledge memorable risks. Much like confronting your fears, acknowledging a memorable risk is the best way to deal with it. Continuing with one of our examples, suppose you are representing Exxon Corporation on the issue of oil supertanker safety. Although the event happened some time ago, most people readily recall the Exxon Valdez. It was a memorable event for millions (perhaps billions) of viewers. If you were in such a situation, perhaps the first thing to do is to acknowledge the Exxon Valdez early on in the communication. Ignoring it may simply add to the potential outrage.

dreaded vs. not dreaded risks

Dread refers to the fear or terror associated with certain outcomes. Compare these two outcomes: dying peacefully in your sleep, or being killed and eaten by a tiger. Many people would prefer the first outcome to the second, although both incidents result in a death.

The recommendation here is to recognize and legitimate the dread that people already feel. By acknowledging these fears and talking about them in a matter of fact manner, we have a greater chance of keeping them from escalating.

catastrophic vs. chronic risks

This element is concerned with time frames. For example, if all the lung cancers that normally occur in a single year were concentrated on a single Tuesday in Los Angeles, the odds would go up that Congress would ban smoking by that Friday.

This element is related to our tendency to ignore small numbers. The conclusion here is that if you wish to raise outrage, emphasize the risks over a year or, better yet, a lifetime.

Unknowable vs. knowable risks

Uncertainty is scary. However, if research can make a risk more understandable and detectable, it tends to reduce the outrage. Thus, research can play a role in reducing outrage, simply because it is better understood.

outside control vs. individual control of risks

Imagine slicing vegetables with a sharp knife. Think about how close the knife gets to your fingers. However, because you have individual control, you may not have much outrage over this activity. However, now imagine this as a two person operation! You hold the vegetables while someone else uses the knife. Now imagine that the knife is being used by a corporate executive or nameless bureaucrat. This outside control helps explain the kind of outrage that others feel in a variety of risk issues. The conclusion here is that we need to give citizens the power to control more of the risks they face. This is not always easy, it is worth considering because it has such a powerful influence over outrage.

unfair vs. fair risks

When risks are distributed unfairly, they tend to raise outrage. For example, hazardous waste facilities are more likely to be located near black communities than to white communities.

In recent years, the EPA started a program on environmental equity to better recognize and respond to these issues. Notice that the issue is not simply the total number of lives lost, but the distribution of the risks among different groups.

Immoral vs. moral risks

When risk issues are reduced to questions of right or wrong, they tend to raise the outrage. Tradeoffs become irrelevant when morality is in question. For example, imagine that we reduced the cases of child molestation in a community down to 5 children.

If this is a community of 5 million people, is that a success? Not for the 5 children! Of course, reducing risks down to zero may not be possible, but the lesson here is clear: you don't have to achieve zero risk, but you should want to achieve it, and say so.

Suspicious source vs. trustworthy source

A suspicious source (e.g., a used car salesman, or a tobacco company executive) may calculate and express the risk perfectly well, but will still face more outrage than a trusted source. The lesson here is to recruit trusted outsiders to have oversight and involvement is risk issues.

Unresponsive process vs. responsive process

Scientists are notorious for being unresponsive to the emotional aspects of risk issues. After all, scientists are trained to ignore the emotional aspects of technical issues. However, ignoring emotions can simply add to the frustration and outrage a social process. The conclusion here is that scientists often need training to recognize and respond to the emotional concerns of participants. Often this is simply a matter of acknowledging emotions such as anger or fear.

7d. Outrage Factors (part 2)

For the remaining outrage factors, the advice remains the same: anticipate these elements, and acknowledge them when they occur.

vulnerable populations vs. average populations

When children and other vulnerable populations are exposed to risks, outrage tends to increase.

delayed effects vs. immediate effects

Delayed effects may raise outrage because it is more uncertain when they will occur.

affects future generations

This is an even more delayed effect, but is so important in its influence that it deserves a separate category.

identifiable victims vs. statistical victims

Whenever you can put a face to a victim (as opposed to a statistical event), the outrage tends to increase.

Reducible risks vs. preventable risks

Preventable risks have the possibility of being reduced to zero, whereas merely reducible risks are an acknowledgment that people will die. Whenever we can prevent risks, we can reduce outrage.

few benefits vs. many benefits

Products with benefits (e.g., gasoline) may raise less outrage than products with few or poorly understood benefits (e.g.,

media attention vs. no media attention

Media attention may be better viewed as a result variable. In other words, if an issue has raised outrage, the result is likely to be greater media attention.

opportunity for collective action

Otherwise known as mob behavior, whenever there is a possibility for outrage within a large group of people, the outrage tends to feed upon itself. For this reason, it is sometimes advisable to address risk issues one person at a time, as opposed to a public forum.

7E. Risk Comparisons

A great deal of work has been done in the area of risk comparisons (5). The concept is simple enough: we explain a risk by comparing it to a better understood risk. Unfortunately, some risk comparisons create more problems than they are worth. We can think of a hierarchy of risk comparisons – from best to worst. In reviewing the list below, be aware that:

1) risk comparisons should never be primary basis of decisions;

2) multiple comparisons might help overcome problems, and

3) all risk comparisons should be approached with extreme caution.

4) The American Industrial Hygiene Association has taken the position that risk comparisons should be made only when the calculated risks being compared have similar characteristics (9).

FIGURE 30. HIERARCHY OF RISK COMPARISONS

1. Most acceptable approaches are to compare risks with:
   a) standards e.g., EPA, OSHA, etc.
   b) risks at different times e.g., now compared to last year
   c) different estimates of the same risk e.g., ours compared with Sierra Club

2. Less desirable approaches are to compare:
   a) risk of action with no action e.g., if we buy control equipment, if we do not
   b) alternatives e.g., landfill risk is x, incinerator is y;
   c) same risk in other places e.g., L.A. vs. Denver

3. Even less desirable approaches are to compare:
   a) average risk with a peak risk e.g., exposures at home vs. at the plant gates
   b) specific risk to all sources of an effect e.g., 3% of the total lung cancer risk

4. Marginally acceptable approaches are to compare:
   a) cost e.g., reducing risk would cost x dollars
   b) benefits e.g., this chemical would save lives in hospital use
   c) occupational with environmental e.g., public vs. in the plant
   d) risks from same source e.g., chemical x compared to y from same source
   e) other risks of same disease e.g., lung cancer from chem. x vs. radon

5. rarely acceptable approaches:
   a) suggest acceptability of risk e.g., chem. x versus driving your car
   b) suggest surrendering of rights e.g., chem. x versus smoking a cigarette
   c) unfamiliar risk of a familiar activity e.g., chem. x versus aflatoxin in peanut butter

Refining the analysis:

Public information programs can affect risk perceptions (6), and these perceptions in turn can affect public policy (7). Even well-intended, scientifically accurate messages can have unintended consequences due to the role of risk perceptions. A good example of this effect is the attitudes towards energy alternatives such as nuclear power or fossil fuels. Nevertheless, the following conclusions about outrage factors can guide us in refining our understanding of risk perceptions.

A. Risk is more than the assessed hazard. It is a combination of hazard and outrage. Therefore, a risk analysis is always refined when we consider the hazard in the context of outrage factors.

B. The public responds more to outrage than to assessed hazards. It is more direct and less technical. Therefore, when a risk analysis is being released to the public, refinement means taking a closer look at perceptions.

C. Activists and media amplify outrage, but they do not create it. If a risk had no outrage associated with it, there would be less attraction of activists and media. Therefore, a consideration of outrage factors will refine and improve any contact with activists and the media.

D. When hazards are high, risk communicators should nurture outrage. When hazards are low, risk communicators should reduce outrage. In other words, the outrage should be appropriate to the hazard. Rather than simply responding to outrage, this refinement considers the appropriate use of outrage factors.

E. Companies and agencies usually cannot reduce outrage until they change their own organizations. Without such change, employees will continue to commit the same errors that inadvertently raise outrage. In other words, refining the analysis means taking a closer look at the organization.

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 7a

1.Bias refers to a prejudice or inclination towards a particular conclusion.

2.Risk biases can include the ignoring of assumptions, uncertainty, and tradeoffs.

3.To capture people's attention, we should choose units that result in smaller numbers.

4.Hindsight bias assumes that the past always predicts the future.

5.Adding details to a risk makes it seem more plausible.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 7b

1.Representativeness refers to the ease of imagining or recalling an event.

2.Availability refers to the similarity of new events to known processes.

3.Anchoring means we tend to stick with our first numerical estimate.

4.Reporting statistical power (type two error) can help prevent representativeness.

5.Risk assessments may help prevent the availability bias.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 7c

1.On average, industrial sources tend to raise more outrage than natural.

2.On average, memorable risks tend to raise more outrage.

3.On average, catastrophic risks tend to raise more outrage than chronic.

4.On average, unresponsive processes tend to raise more outrage.

5.On average, identifiable victims tend to raise more outrage than statistical ones.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 7d

1.Risk is not just hazard, but also outrage.

2.The public responds more to outrage than to hazard.

3.When hazards are high, risk communicators should nurture outrage.

4.Opportunity for collective action tends to raise outrage.

5.Delayed effects tend to raise more outrage.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 7e

1.Comparing risks with standards is generally more effective than comparing risk of action with no action.

2.Comparing risks at different times is generally more effective than comparing alternatives.

3.Comparing different estimates of the same risk comparing with same risk in other places.

4.Comparing to cost is generally more effective than comparing average risk with a peak risk.

5.Comparing occupational with environmental is generally more effective than comparing specific risk to all sources of an effect.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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Chapter 8: Risk Communication

When it goes well, risk communication seems natural, intuitive, and almost effortless. When it goes badly, effective risk communication can seem impossible. However, good risk communication happens all the time. Some of the techniques discussed in this section are well known (1), but a systematic approach may help generate a more thoughtful risk communication process. Of course, risk communication is a concern not only to agencies, but also to industry, public interest groups, and citizens in general (2-4). The techniques listed here provide the basics, but it is also important to recognize that the field of risk communication is rapidly growing.

Terms and Concepts:

noise
- message problems
- source problems
- channel problems
- receiver problems

risk communication objectives
- information
- behavioral change
- emergency response
- negotiation

8A. Introduction

Many excellent references are available for risk communication training (1-4), but practitioners are also interested in summaries of these techniques. This chapter presents a taxonomy of risk communication to help meet this need. It is a quick reminder rather than complete training, and of course it cannot replace professional experience. A more important reason for this taxonomy, however, is that our profession needs a framework for incorporating the expanding literature of risk communication. Thus, this taxonomy is intended to serve the dual purpose of reference guide and framework for debate.

There is no small controversy over the proper framework for viewing risk communication research. Some researchers believe that two schools of thought are emerging: cognitive models and planning models (5). While these two frameworks are not mutually exclusive, this section emphasizes the latter framework and relies on a traditional model that divides communication into four parts: a source transmits a message to a receiver through various channels. Channels include television, newspapers, public meetings, and a growing number of approaches. Sources and receivers can be individuals or groups. The most crucial point here is that good risk communication is more than a clever message -- it is an interactive exchange that depends on all the model elements.

This taxonomy adds a second dimension based on traditional management operations (planning, organizing, staffing, directing, and control) (6). This chapter adapts these operations to risk communication techniques. Planning emphasizes the commitment to clear objectives as well as the timing of communication. Organization focuses on legal, social, and political roles in risk communication. Staffing considers how to adapt the person to the task, and the task to the person (both inside and outside the organization). Directing considers the leadership, experimentation, and negotiation that are essential for progress. Control is primarily concerned with evaluation methods.

The appropriate context for these guidelines should include these warnings:

1. risk communication techniques are labeled as strategies, not solutions. This is in deference to the art of risk communication. A mechanical application of these techniques will not solve every risk communication problem; indeed, no approach can guarantee such results in risk communication.

2. taken by itself, strategies may appear as simplistic platitudes. However, it is intended as a quick reminder of techniques in the literature. Further readings on both problems and strategies are provided at the end of this chapter.

8B. Source Issues

1A **Planning** One of the biggest problems in planning is to establish the need for risk communication. It can be tempting to bypass different publics on difficult technical decisions. Nevertheless, we should respect publics for their political power. A healthy respect for this power is a practical starting point to selling risk communication. This concept is formally recognized in various right-to-know laws. Informally, environmental health professionals have long been involved in communicating risks with the public.

All too often, professionals misunderstand or disagree about the actual objectives of risk communication. This is crucial, because objectives help define the success of risk communication. For example, most objectives in environmental health are not simply to inform, but to change behavior (a far more difficult task). In addition, a growing number of risk communication issues (especially where laws are vague) place environmental health professionals in a negotiation context. The literature distinguishes strategies that address these different objectives. Experience can also guide formation of realistic objectives.

Time pressures seem universal. The recommendation to "plan ahead" may appear too convenient for this taxonomy, but a never-ending series of crisis deadlines is often a symptom of poor planning.

1B. **Roles** The law often places limits on risk communication activities. In such cases, it is especially important to explain your professional role within the law. Nevertheless, public concerns often remain at an emotional level. Most experts believe it helps to acknowledge other's emotions and even to show some of your own emotion. The use of examples and anecdotes in explaining codes can be especially effective. Finally, every role should have adequate authority to match the assigned responsibilities.

1C. **Staffing** Common to younger staff is the problem of weak credibility. However, anyone can encounter this problem, and the advice is universal -- enlist other credible sources. This may include a careful documentation of existing codes and technical literature. However, it should also include other professionals. Personal pride may keep us from relying on other individuals, but we should see ourselves as part of a professional network.

Although environmental health professionals are as skillful at risk communication as many of the purported experts, there are various ways to build on this expertise. Organizational policies and procedures in risk communication should guide agency actions. Indeed, this taxonomy may help derive specific policies tailored to the needs of an organization. In addition, a small library can form the basis for developing small seminars with case studies. Accompaniment by a senior member on difficult cases can also increase expertise.

1D. **Leadership** The media often wants answers when an investigation is midstream. If an agency allows different members to speak to the media (or to critical groups), this often leads to so-called "conflicting reports" (real or imagined). Even when conflict in an organization is genuine, a wise approach is to appoint a single credible spokesperson on the most sensitive

issues. Honest debate should still proceed, but it weakens the entire agency when it is labeled "conflicting reports." For potential conflicts among agencies, individuals should be appointed to coordinate with various authorities.

1E. **Evaluation** If professionals are sincere about a pro-active approach to risk communication, there are various techniques for evaluating individual strengths and weaknesses (9). Based on these evaluations, ongoing training can be devised to improve risk communication skills.

8C. Message Issues

2A. **Planning** There is no single definition of risk. It is defined differently among organizations and individuals, depending on their objectives. Thus, it is crucial to state your assumptions about risk. Most publics are more interested in the qualitative concerns and political issues around risk (especially outrage factors) (4). We should anticipate any special factors related to these objectives.

2B. **Roles** In our search for placing risk in a proper context, it is tempting to make comparisons with other known risks such as smoking, driving, or flying a plane. Research tells us to be extremely cautious about risk comparison (2). The most acceptable approaches include comparisons with legal standards. The worst examples are those that imply the acceptability of a risk (for example, risks compared to smoking may imply that smokers should accept all risks that are less than smoking). When risk comparisons do work, the role or intent of the comparison is usually well understood.

2C. **Staffing** Uncertainty is inherent to our work. Rarely can we predict morbidity or mortality with absolute certainty. Even when people demand absolute answers, we must acknowledge this uncertainty by explaining data gaps, levels of confidence, and expert disagreements. That is our professional responsibility. In return, expert opinion is often accorded specific powers to staff by various laws. Thus, uncertainty does not always preclude action. While this is open to legal cross-examination, recent research supports the use of expert opinion -- it can even outperform computer programs (10).

As with any profession, environmental health has its jargon. For written communications, computer programs can help reduce jargon (commercially available programs include RightWriter and Grammatik). For the spoken language, observing the work of successful risk communicators can also help.

Even when we cut the jargon, complex scientific concepts are part of many environmental health issues. A supporting document (sometimes called a "white paper") that includes definitions and explanations can help. Brochures and fact sheets are also part of the same strategy.

2D. **Leadership** There is some controversy about what constitutes a complete risk message, but most experts agree that risk messages should include practical actions for individuals (what

would you do when faced with this risk) and legal context (what agencies can and cannot do). Other considerations include estimates of benefits as well as risks, the uncertainty of these benefits and risks, and different measures of risks. Leaders should be responsible for defining a complete message.

2E. **Evaluation** Even with good intentions, we are all prone to biases in reports. While we may never eliminate bias, we can control it by independent review of risk communication. Furthermore, authors should be accountable for their writing.

8D. Channel Issues

3A. **Planning** Poor media relations can harm everyone. While other techniques in this taxonomy can help, perhaps the most important technique is to formally plan to improve long term relationships with the media. In the short term, everyone is vulnerable to unfair news reports, but by considering media needs (especially deadlines) and responding favorably to fair reports (sometimes with a quick phone call to the reporter), we may improve long term relationships.

3B. **Roles** The media is well known for sensationalizing risks -- death, politics, and scandal continue to sell newspapers and other media. Indeed, one of the true roles of media is to sell their product. That is why we must study what makes a story newsworthy. If we can anticipate the most volatile aspects of a story, we can prepare a pro-active stance on these issues. While this will not eliminate sensationalism, it is far more effective than reacting to a crisis.

3C. **Staffing** A communication breakdown is when people do not receive needed information, or they simply do not believe the channel of information. In emergencies, it is especially important to allow for confirmation needs. Sometimes a 1-800 number is useful. Other times it is simply a matter of providing multiple channels for the same information (for example, telephone, brochures, and TV).

3D. **Leadership** The choice of proper channels (large meetings, numerous small meetings, television, and so on) is becoming even more challenging with emerging technologies such as e-mail. In general, the large, public meeting is not the best channel for conveying technical information. It will take leadership to experiment with these technologies to determine the most effective channels for a particular organization.

3E. **Evaluation** Inaccurate news reports can be damaging, even if they are not sensationalized. By studying what the media knows (it varies), we can provide background material to help improve accuracy. With consistent follow-up on reports, we may even reduce inaccuracies.

8E. Receiver Issues

4A. **Planning** Despite dramatic news reports, the opposite problem of apathy is perhaps more serious. How do we get people excited about the significant risks? The key is to listen to your audience. You can attract attention by addressing their concerns and misconceptions. This is the heart of the cognitive models approach. Again, these are techniques, not a panacea; but careful listening is at the heart of understanding the receiver.

A macro-objective applies to society, and it is the work of agency officials. A micro-objective, in this case, is an individual's objectives. When agency officials talk to individuals about risk, we should always relate policies to individual actions: specifically, always prepare an answer to the question "what would you do?" If time pressures are inherent to the job, a common mistake is to overload people with information. This tends to weaken comprehension.

4B. **Roles** Mistrust is perhaps the single most important receiver factor in risk communication. If publics do not trust government officials, for example, agency roles are weakened. Dishonesty (perceived or real) is the biggest destroyer of trust. In a multicultural society, there are limits to how much we can identify with each other by norms of dress, language, and behavior. Still, within reason this approach can also help.

4C. **Staffing** Most human beings, even the motivated ones, are poor listeners. By repeating your message, especially over multiple media (TV, radio, papers), messages can reach a broader audience.

Even with the best efforts, the sad truth is that most Americans are illiterate about risk. We need more "consumer guides" on various risk issues, written by and for public groups (with help from environmental health professionals). On the positive side, the literature shows that, if motivated, a surprising range of people can eventually understand risks. Whether they agree with agency decisions is a separate issue, but an adequate understanding of the risks, regardless of the conflict, is a critical part of risk communication.

4D. **Leadership** Even after successful efforts, problems can occur after key decisions are made. If we involve publics early, we can reduce the chances of this. Furthermore, we should leave room for new options when issuing decisions on sensitive issues (for example, draft documents distributed for review).

4E. **Evaluation** Public responses to risk communication can be wildly unpredictable, so how can we anticipate problems? First, we must abandon the concept of a single "public." There are many publics of widely varying attitudes and education. We can study different publics by pre-testing and post-testing written communication. Orally we can rely on interviews or focus groups. Finally, the more we understand hidden agendas, the more we can predict responses.

Refining the analysis:

The best way to refine and improve our risk communication is to constantly evaluate it. The taxonomy in this chapter summarizes the means for evaluation, but other references are available to support this task.

There are times when expert intuition can be more effective in predicting risk than any other technique. The challenge is to communicate that intuition in an effective way. Intuition can be based on complex scientific insights that are not easily articulated, even to the scientist.

Thus, misunderstandings of a risk message are not simply a failure due to technical ignorance. A good example of this effect is the labeling of microbial risks (9).

Given these many different problems and strategies, it may seem impossible to be a good risk communicator. However, good risk communication happens all the time. Some of the techniques listed here are well known, but we can always be on the lookout for new techniques.

The techniques listed cannot be comprehensive, because the field of risk communication is rapidly growing. Furthermore, a taxonomy does not capture the intricate interactions of multiple problems and strategies. Nevertheless, it is a starting point for professionals in the field.

Like all taxonomies, it should be expanded and revised by the very people who use it. For example, as management theories develop, there may be more useful ways of classifying the management side of the taxonomy. Furthermore, as theories for mental models develop, new ways of classifying risk communication strategies may also develop.

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 8a

1.Channels of communication can include the internet.

2.Sources and receivers can only be examined at the individual level.

3.The sole concern of risk communication is the message.

4.Organization theory focuses on legal, social, and political roles in risk communication.

5.Control is primarily concerned with evaluation methods.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 8b

1.The need for risk communication has been formally recognized in various right-to-know laws.

2.The sole objective of risk communication is to inform.

3.Credible sources may include existing codes and technical literature.

4.Training can be devised to improve risk communication skills.

5.Most experts believe it helps to acknowledge other's emotions.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 8c

1.There is no single definition of risk.

2.Research tells us to be extremely cautious about risk comparisons.

3.Uncertainty does not always preclude action.

4.When possible, there should be independent review of risk communication.

5.Authors should be accountable for their writing.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 8d

1.One of the most important communication techniques is a formal plan to improve relationships with the media.

2.One of the true roles of media is to sell their product.

3.Sometimes it is useful to provide multiple channels for the same information.

4.In general, the large, public meeting is not the best channel for conveying technical information.

5.We can provide background material to help improve accuracy.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 8e

1.A micro-objective, in the case of receivers, is an individual's objectives.

2.Always prepare an answer to the question "what would you do?"

3.Mistrust is perhaps the single most important receiver factor in risk communication.

4.The literature shows that, if motivated, a wide range of people can understand risks.

5.There are many publics of widely varying attitudes and education.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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Updated online information at http://www.csun.edu/~vchsc006/469/0.html

Chapter 9: Risk Management

Risk management is the process of making decisions and taking action to resolve risk issues. The Presidential/Congressional Commission on Risk Assessment and Risk Management (3) summarizes this in the following six steps:

1. Define the problem and put it into context,
2. Analyze the risks associated with this problem,
3. Examine options for addressing the risks,
4. Decide which options to implement,
5. Take action to implement the decision, and
6. Evaluate the actions results.

This framework emphasizes collaboration with stakeholders and iterations of this processes as new information and insights are obtained. These iterations are not inconsistent with the cycle of risk analysis illustrated in figure 1. This framework entails, at a minimum, an integration of risk attitudes, ethics, economics, and law into these decisions. The history of risk management in the United States offers lessons for improvement (1), and one of the key challenges is that that these various inputs are integrated into decisions (2).

Terms and Concepts:

risk attitudes:
- Pessimist's decision model
- Optimist's decision model
- Minimization of regret model
- Maximization of average payoff

ethical models of risk:
- Utilitarian
- Egalitarian
- Elitist
- Libertarian

economic models of risk
- Willingness to pay
- Equitable allocation
- Human capital
- consumerism

risk management options:
- advisory
- technological
- economic
- regulatory

sensitivity to intervention

9A. Risk Attitudes

We can distinguish **risk attitudes** by presenting a hypothetical decision within a matrix. A sample decision matrix given below clarifies the decision problem:

FIGURE 31. HYPOTHETICAL RISK DECISION

	50% chance of:	50% chance of:
Landfill	9 deaths	1 death
Recycling	8 deaths	2 deaths
Incinerator	7 deaths	3 deaths

Reading off this matrix, for example, the landfill option has a 50% chance of 9 deaths and a 50% chance of 1 death. There are four possible approaches to deciding among the landfill, recycling, and incinerator options.

1. The first is called the **pessimist's decision model** (and is also called "maximin" criterion). The procedure is simple enough:

   A. Determine worst outcome for each action
   B. Select the action with best of these values

In the earlier example, we select the worst outcomes as follows:

FIGURE 32. PESSIMIST'S DECISION MODEL

Landfill	9 deaths	1 death
Recycling	8 deaths	2 deaths
Incinerator	**7 deaths**	3 deaths

Notice 3 changes from the earlier matrix: 1) we no longer show the 50% chances in the top row, because these risks are *irrelevant to the pessimist*! 2) we focus on the worst outcomes (with the bold borders in the matrix), because those are the most pessimistic outcomes; and 3) the best choice, given in bold print, is 7 deaths. From here, we select the incinerator, because it results in the fewest deaths. Beware, however, of falling into the trap of assuming that the pessimist wants to maximize deaths! If that were the case, we would select the landfill. Instead, when faced with a risky event (e.g., 9 versus 1 death), the pessimist assumes the worst *outcome* as the basis for analysis.

2. The second model is called the **optimist's decision model**. The procedure is also simple enough:

   A. Determine best outcome for each action.
   B. Select the action with the best of these values.

FIGURE 33. OPTIMIST'S DECISION MODEL

Landfill	9 deaths	**1 death**
Recycling	8 deaths	2 deaths
Incinerator	7 deaths	3 deaths

This time, we focus on the most optimistic outcomes. Again, the probabilities are irrelevant here. From this table, we then select the landfill because, with one death, it has the least number of deaths.

3. The third model is called the **minimization of regret model** (also called the "minimax" criterion). It operates under the concept of opportunity cost in the following way:

   A. Determine outcomes for each "state of nature" (i.e., worst and best outcomes).
   B. Compute the opportunity cost for each state of nature.
   C. Find the maximum opportunity cost for each action.
   D. Select the action with the minimum of the above opportunity costs.

FIGURE 34. MINIMIZATION OF REGRET MODEL

State of Nature:

	worst	best
Landfill	9 deaths	**1 death**
Recycling	8 deaths	2 deaths
Incinerator	**7 deaths**	3 deaths

Opportunity Cost (regret):

	worst	best	Maximum regret
Landfill	2 deaths	0 death	2 deaths
Recycling	1 death	1 death	**1 death**
Incinerator	0 deaths	2 deaths	2 deaths

Notice that the first table looks the same as the previous tables, but we have labeled them the best and worst outcomes (i.e., "states of nature"). Instead of being optimistic or pessimistic, we look at both. With states of nature, we pretend that the events have already occurred. In other words, how will we evaluate these options *after* the fact?

We do this by developing a second table to compute the opportunity cost (also called regret) for each option. For example, under the worst state of nature, the best choice is incinerator. Although there are 7 deaths, had we chosen the incinerator, we would have no regrets *relative to the other choices*.

Under the worst state of nature, the landfill has 9 deaths compared to the incinerator with its 7 deaths. Thus, with the landfill we have a regret of two additional deaths. Using this technique of comparing each state of nature with the best possible outcome in that category, we label the regret associated for each state of nature and each option.

We then focus our attention on the boxes with the bold borders that are labeled maximum regret. The highest regret possible for each option is two, one, and two respectively for the landfill, recycling facility, and incinerator. Hence, the recycling facility is the best choice under this model, because it minimizes the regret that may occur in the future.

4. The last model is the **maximization of expected value,** which works in the following way:

A. Determine average for each outcome (expected value).
B. Select best option.

Since all three options have an average of 5 (e.g., (9+1) / 2 = 5 for the landfill), then all three options are tied. We can feel free to select any one of them.

Note that it was possible to select any of the three alternatives, and even to declare them tied, under these four models towards uncertainty. Hence, the underlying attitudes towards uncertainty may have more influence on the decision than the risk assessment itself.

9B. Ethical models

These four ethical models are based on the concept of utility, or how we assign value to events or commodities. Utility is especially applicable to risky events. If we assign a sub-value such as y (i.e., Uy), we refer to this as "the utility of individual y." In a diverse society, Uy and Uz can be used to describe the range of utility within a society for a single event. These models differ in how they address these differing utilities. The critical ethical question is: how do we use each of these models to resolve the conflicting utilities for risky events? While the discussion here is theoretical, it is clear that there are high risk and low risk individuals for most risky events (4).

The **utilitarian model** is based on the goal of maximizing utility within a society, represented by:

Maximize {Uy + Uz}, where:

U = utility
y,z = individuals y and z.

This model emphasizes the total utility to society, as represented by adding of utilities. Well known proponents of this ethic are Jeremy Bentham and John Mill. Notice that there is no concern about the distribution of utility – individual y may be very happy with the events (high utility) and individual z may be very unhappy with events (low utility), but as long as the total utility is maximized, the utilitarians argue that social decisions are optimal. This approach is in line with Cost-Benefit Analysis, which seeks to maximize the utility of a decision for society.

The **egalitarian model** addresses the problem of distribution by:

maximizing the minimum of {Uy, Uz}.

In other words, the egalitarian must know who has the least utility in a society. A simpler way of saying this is "who is the poorest member of society." Thus, this model emphasizes aiding the least fortunate in society. Another way of looking at this is "a chain is as strong as its weakest link" and society is only as good as its poorest citizen. Recent developments in the area of *environmental equity* are a classic example of the egalitarian model.

The **elitist model** takes the opposite approach by:

maximizing the maximum of {Uy, Uz}.

This model emphasizes advancing the most promising members of society as a means for advancing the society. This can be viewed in different ways. On the one hand, it can be seen as a way of "making the rich richer and the poor poorer," since it favors those who already have a high utility. On the other hand, it can also be seen as "society is as good as its richest citizens." In extremely poor countries, the argument has been made that limited resources can have a greater impact on economic development if they go to the wealthiest sectors of society.

The **libertarian model** is based on the goal of:

increasing both Uy and Uz over time.

This model emphasizes that actions are justified if no one is harmed. The libertarian model is often seen in western societies, particularly ones with widespread news coverage. Any individual who is harmed is easily a feature story, and the collective outrage of a society may push for reforms. However, the libertarian society is *not* the same as the utilitarian model. The utilitarians are interested in increasing *overall* wealth, while the libertarians want to see *uniform* improvement.

9C. Economic models

The first economic outgrowth is called **willingness to pay**. This approach distributes risk according to an individual's willingness to pay, and relies heavily on the concept of a free market. This approach is a direct outgrowth of the utilitarian ethic and cost benefit analysis. It treats risk as a commodity that can be bought and sold, and therefore the way to assign economic value to this commodity is based on willingness to pay. The advantage to this approach is to "give people what they want." The chief disadvantage is the consequences of a true willingness to pay. The problem with this approach is that some members of the public may not be able to afford to purchase a lower risk, and many members of society may not fully understand the risks. For example, there is a booming international business in cigarettes, cocaine, and even hamburgers. This is evidence that willingness to pay does not always act to minimize risks. People are quite willing to pay for sometimes notorious and sometimes subtle agents of risk.

The second approach is called **equitable allocations**. This approach focuses on the distribution of risk, and seeks to place a higher priority on the worst risks. The advantage of this approach is that we address the worst problems first. There is a sense of fairness in seeking equity. As such, it is closely associated with the egalitarian ethic. We see many examples of this approach -- for example, if we create a priority list of hazardous waste sites and spend money on the worst ones first, this is equitable allocation at work. The biggest disadvantage is, of course, who decides what is worst, and on what basis? It is very difficult to compare expenditures for hazardous wastes, for example, with drug abuse programs, defense spending, and the range of expenditures in a society.

The third approach is called **human capital**. This approach distributes risk to maximize contribution to capital. It can be seen as a form of pure capitalism. At its extreme, an individual's worth is measured by their contribution to GNP -- the greater their value, the more entitled they are to the protections from risk. The advantage to this approach is that it can maximize the GNP growth of nations. The chief disadvantage is fairly obvious -- it seems inherently unfair to the poor, because they are treated as less valuable to society as the rich. For this reason, this approach is most closely associated with the elitist ethic.

The fourth approach is called **consumerism** or **environmentalism**. This approach seeks to minimize risk to satisfy consumer demands. This approach differs from the all the previous approaches in that it rejects economic arguments. The difficulty of this approach is in deciding how to distribute resources when there is a lack of economic guidance.

One last point: none of these systems works perfectly all the time. Instead of thinking about which system is closest to your personal preferences, it is perhaps a better exercise to imagine circumstances where you would prefer each of the above systems.

9D. Legal models

The first legal approach is one of **economic incentives**. The fundamental argument of this approach is that you must pay for the risks you impose on others. Various economic tools may be applied to achieving risk goals: 1)effluent discharge fees or fines, 2) compensatory approaches (insurance), 3) economic incentive to companies to prevent pollution, and 4) subsidies.

The advantage of this approach is that it gives producers the freedom to select the approaches for controlling pollution. This approach is typified by the RECLAIM program (Regional Clean Air Incentives Market) in Los Angeles California, as implemented by the South Coast Air Quality Management District. The disadvantage is that it may without the capacity to control pollutants, the economic incentives cannot drive risk controlling behaviors.

The second approach is to use **traditional regulations** as implemented by any number of major laws: the U.S. Clean Air Act, Clean Water Act, and so on. These include emission standards and ambient standards. The biggest advantage is that this form of legal control has the most history and is most familiar to people. The disadvantage is that it is expensive to enforce, and regulators are looking for more effective ways of achieving risk goals.

The third legal approach is **advisory methods**. This approach provides information to the public on: the existence of risks, and the possible means of avoidance (e.g., reducing radon exposures). As such, it does not intervene in private transactions. In other words, there is no enforcement. An advantage to this approach is that when a risk is not very well understood, we can provide the information we have and let people decide for themselves. The disadvantage, of course, is whether people will voluntarily follow recommendations. This information is most effective when it is consistent with individual perceptions of risk.

The fourth approach is the **technological approach**. This approach seeks engineering solutions to risk problems and is typified by the requirements for best available technology for water treatment, air pollution control, and so on. The biggest advantage to this approach is that engineering is typically the solution to risk problems, and this approach focuses on the eventual solutions. The problem is that even with the best technologies for risk controls, the risks may still be unacceptable to the public.

9E. Integrating the models

The most challenging aspect of risk management is integrating the previous components. For example, are we analyzing an economic problem when the true problem is a legal one? Are we analyzing individual risk attitudes when the real question is justifying the ethical basis for a decision? Are we defending a risk assessment when the true problem is that the risk communication has dramatically altered the perceptions of the intended audience?

Answers to these question depend on our ability to have an integrated view of the components. This section explores some of the potential interactions between the previous sections. Some obvious connections come to mind:

1. Equitable contributions are consistent with egalitarian ethics.
2. Economic incentives are based on willingness to pay.
3. Willingness to pay models are consistent with utilitarian ethics.
4. Advisory laws, by lacking enforcement, tend to support elitist ethics.
5. Consumerism, in its rejection of economic arguments, is closely associated with libertarian ethics.

I invite you to think of other permutations that extend beyond this discussion.

1. If the risk assessment is poor or the risk communication has been ineffective, risk management will be compromised.
2. Risk communication influences risk attitudes, and risk attitudes influence risk management.
3. The kind of economic or legal incentives that work in one nation may not work in another because of the mix of risk attitudes, risk ethics, and risk communication, not to mention the assessed risks themselves!

Keep in mind that the difficulty of integrating these approaches is that the risks may be poorly understood, the issues may still be evolving, and the viewpoints expressed in these sections are not so pure for most people. In other words, there may be a little bit of pessimist and optimist in all of us, but it depends on the information we have at hand.

Finally, "sensitivity to intervention" refers to our ***ability*** to lower the risks. Risk management should be focused on areas that are most sensitive to intervention. For example, consider the risk of a meteor striking the earth's surface. Virtually nothing can reduce the likelihood or consequence of such an event. Consequently, little or no effort should be expended towards this risk, simply because it would be wasted. Another example is bad weather. While risks related to weather hazards may be controlled through better forecasting, planning, and preparation, the weather itself is not sensitive to control. Thus, by addressing factors with higher sensitivity, we hope to maximize the effectiveness of risk management.

Refining the analysis:

Risk communication and risk management are interdependent: the improvement of decisions depends on the improvement of communication (5), and the improvement of communication is dependent on good decisions (6). Guidelines for refining the analysis here can be drawn from principles of policy analysis (7):

1. Consult the literature, the client, experts, and stakeholders.
2. Let the problem drive the analysis.
3. Make the analysis as simple as possible, but no simpler.
4. Identify all assumptions.
5. Identify decision criteria.
6. Identify uncertainties.
7. Perform sensitivity and uncertainty analysis.
8. Refine the analysis.
9. Document clearly and completely.
10. Obtain peer review.

Quizzes:

Answer the following questions as true or false.
Be prepared to discuss your answer

Quiz: module 9a

1.For questions 1-5, suppose plan A has a 50/50 chance of 1 death or 9 deaths, and plan B has a 50/50 chance of 2 deaths or 6 deaths.
For the expected value model, the best choice is: plan A.

2.For pessimists, the best choice is: plan A

3.For optimists, the best choice is: plan A

4.For minimization of regret, the best choice is: plan A

5.Pessimists and optimists will always disagree on which risky option is the best choice.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 9b

1.For questions 1-5, suppose there are two communities of equal population. A new policy will decrease risk in the poorer community by 1% but increase risk in the richer community by 2%. The status quo is for risks to remain the same for all parties. The utilitarian will oppose this policy.

2.The egalitarian will oppose this policy.

3.The elitist will oppose this policy.

4.The libertarian will oppose this policy.

5.These groups will never agree on any policy.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 9c

1.Consumerism is a rejection of quantitative, economic approaches to risk management.

2.Human capital attempts to distribute risks so as to maximize contribution to capital.

3.Willingness to pay can be applied to corporate presidents as well as to the individual taxpayer.

4.Equitable allocations mean that everyone pays the same.

5.Willingness to pay is based on individual contribution to GNP.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 9d

1.Advisory models emphasize the use of best available technology.

2.Economic incentives require the support of traditional regulations.

3.Economic incentives require the use of best available technology.

4.Traditional regulations can be supplemented with advisory approaches, economic incentives, and technological approaches.

5.Economic incentives are just a form of an advisory approach.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

Quiz: module 9e

1.Willingness to pay models are associated with utilitarian ethics.

2.Advisory laws can be associated with elitist ethics.

3.Consumerism is associated with libertarian ethics.

4.Equitable contributions are associated with egalitarian ethics.

5.Economic incentives are based on willingness to pay.

Answers on: http://www.csun.edu/~vchsc006/469/0.html

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7. Morgan, M.G. and M. Henrion, Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis, p. 37, Cambridge University Press, 1990.

For more information:

President's Commission on Risk Assessment and Risk Management: Report. Washington: U.S. Government Printing Office, 1996.

Updated online information at http://www.csun.edu/~vchsc006/469/0.html

Appendices

Appendix 1. Poisson Table

95% Confidence Interval for a Poisson Variable (Xt)

CASES	LOWER	UPPER
0	0	.69
1	.025	5.57
2	.242	7.22
3	.619	8.77
4	1.09	10.24
5	1.62	11.67
6	2.2	13.06
8	3.45	15.76
10	4.8	18.39
15	8.4	24.74
20	12.22	30.89
25	16.18	36.9
30	20.24	42.83
35	24.38	48.68
40	25.58	54.47
45	32.82	60.21
50	37.11	65.92

- adapted from: : Pearson E.S. and H.O. Hartley, eds., Biometrika Tables for Statisticians, Vol. 1, Cambridge University Press, 1966

- If cases are in between the numbers listed, a linear interpolation can estimate the value. This table is for demonstration purposes only, and the analyst is encouraged to use more accurate tables available on various computer programs (and the web site for this book).

- This table assumes $p \leq 20\%$ and $Nt \geq 50$

Appendix 2. Normal Table

p-values in One Tail Test of a Standard Normal Curve

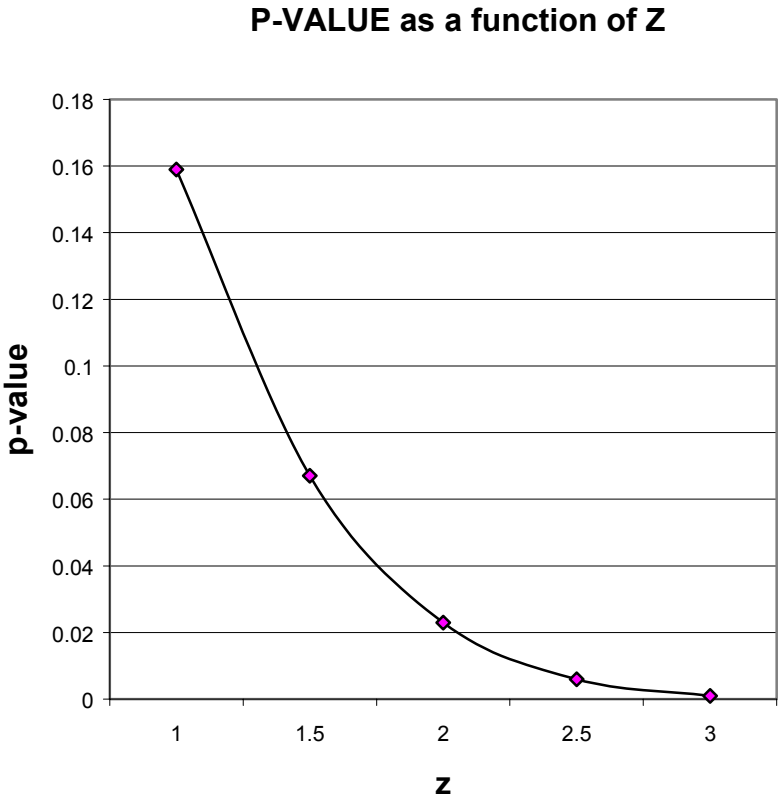
$$z = \frac{Pt - Pc}{\sqrt{pq(\frac{1}{Nt} + \frac{1}{Nc})}}$$

where:

Pt = Xt / Nt = risk to test group
Pc = Xc / Nc = risk to control group
p = [Xt + Xc] / [Nt + Nc]
q = 1-p

z	P-VALUE
0.0	.500
0.5	.309
1.0	.159
1.5	**.067**
1.6	**.055**
1.7	**.045**
1.8	**.036**
1.9	**.029**
2.0	**.023**
2.1	**.018**
2.2	**.014**
2.3	**.011**
2.4	**.008**
2.5	**.006**
3.0	.001

- adapted from: Pearson E.S. and H.O. Hartley, eds., Biometrika Tables for Statisticians, Vol. 1, Cambridge University Press, 1966.
- Numbers in bold font represent the most sensitive area of the curve. If cases are in between the numbers listed, a linear interpolation can estimate the value. This table is for demonstration purposes only, and the analyst is encouraged to use more accurate tables available on various computer programs (and the web site for this book).
- In order to visualize the p-value as a function of Z, a graph is shown on the next page.


P-VALUE as a function of Z
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
p-value
1
1.5
2
2.5
3
z

Appendix 3. TOXNET and IRIS

TOXNET is an acronym for the Toxicology Data Network. It features computerized and online database files oriented to toxicology. The network is managed by the National Library of Medicine. The following files are available on the TOXNET system.

HSDB	(Hazardous Substances Data Bank) Toxicology of over 4500 potentially hazardous chemicals. Emergency handling procedures, environmental fate, human exposure, detection methods, and regulatory requirements. Fully referenced and peer-reviewed by a Scientific Review Panel composed of expert toxicologists and other scientists.
TRI	(Toxic Chemical Release Inventory) Annual estimated releases of toxic chemicals to environment (mandated by the Emergency Planning and Community Right-to-Know Act). Data include names and addresses of the facilities, and the amount of certain toxic chemicals they release to the air, water, or land or transfer to waste sites. Information on over 300 chemicals and chemical categories Since 1991, pollution prevention data is also reported by each facility for each chemical.
IRIS	(Integrated Risk Information System) Online database built by the Environmental Protection Agency (EPA). It contains EPA carcinogenic and non-carcinogenic health risk and regulatory information on over 600 chemicals. The risk assessment data have been scientifically reviewed by groups of EPA scientists and represent EPA consensus. IRIS also contains EPA Drinking Water Health Advisories and literature references.
RTECS	(Registry of Toxic Effects of Chemical Substances) Toxic effects data on over 135,000 chemicals. Both acute and chronic effects, including data on skin/eye irritation, carcinogenicity, mutagenicity, reproductive consequences, and multiple dose studies
CCRIS	(Chemical Carcinogenesis Research Information System) Contains scientifically evaluated data derived from carcinogenicity, mutagenicity, tumor promotion and tumor inhibition tests on over 7000 chemicals
GENE-TOX	(Genetic Toxicology) Online data bank created by EPA with genetic toxicology test results on about 3,000 chemicals. Selected mutagenicity assay systems and the source. peer reviewed and referenced.
DART	(Development and Reproductive Toxicology) bibliographic database covering literature on teratology and other aspects of developmental toxicology. contains over 30,000 citations published since 1989. DART is a continuation of ETICBACK.
ETICBACK	(Environmental Teratology Information Center Backfile) bibliographic database covering teratology literature. contains over 49,000 citations to literature published from 1950-1989. It is continued by DART.
EMIC	(Environmental Mutagen Information Center) bibliographic database containing over 15,000 citations to literature on chemical, biological, and physical agents tested for genotoxic activity. covers literature published since 1991.
EMICBACK	(Environmental Mutagen) EMICBACK is a bibliographic database on chemical, biological, and physical agents that have been tested for genotoxic activity. contains over 75,000 citations to literature published from 1950-1990.
TRIFACTS	(Toxic Chemical Release Inventory Facts) supplements the TRI series with information related to the health and ecological effects, and safety and handling of these chemicals.

The **TOXNET** Basic Search screens are fairly straightforward. Each database involves the use of three screens: Basic Search, Search Results, and Selected Record. The Basic Search Screen is the starting point. It has an input box to fill in. For more information, see the Help file for each database.

The Search Results Screen presents records meeting your search criteria. You can select an individual record by clicking on it or select several records by clicking the boxes.

The Selected Record Screen displays information on your chemical of choice. A Table of Contents lets you select one or more specific data categories for display. Both the Search Results and Selected Records screens contain a series of buttons with search related options.

IRIS is intended for environmental health professionals who deal with risk issues on a regular basis. IRIS summarizes health risks and EPA information on over 500 specific chemicals. IRIS contains the EPA consensus opinion on potential chronic human health effects related to chemical hazard identification and dose-response assessment. Access to IRIS through TOXNET allows free search capability, Boolean logic, and a variety of online features. Methodologies are peer reviewed by EPA's Science Advisory Board.

The core of IRIS is a collection of computer files that contain descriptive and quantitative information such as:
1) Oral reference dose and inhalation reference concentrations for chronic non-carcinogenic health effects, confidence statements, and EPA scientific contacts.
2) Oral slope factors and unit risks for chronic exposure to carcinogens, statements of confidence, uncertainties, and EPA scientific contacts.
3) Drinking water health advisories.
4) EPA regulatory action summaries.

IRIS does not provide situational information on instances of exposure. It directs users to the underlying animal and human data on which this risk information is based. Because of the assumptions and uncertainties used in risk assessment, IRIS risk information should be used carefully and with scientific judgment. Addresses and phone numbers for relevant contacts are listed below.

1) National Center for Environmental Assessment - Cincinnati Office
   Environmental Protection Agency, Office of Research and Development
   National Center for Environmental Assessment
   26 West Martin Luther King Drive, Cincinnati OH 45268 USA
   Telephone: 513-569-7254 Fax: 513-569-7159
2) TOXNET, IRIS Representative, Specialized Information Services, National Library of Medicine
   8600 Rockville Pike, Bethesda MD 20894 USA, toxmail@tox.nlm.nih.gov
   Hours of Service: 8:30 a.m. - 5:00 p.m. (EST) M - F
   Telephone: 301-496-6531 Fax: 301-480-3537
3) Order Desk, National Technical Information Service
   5285 Port Royal Road, Springfield VA 22161 USA
   Telephone: 703-487-4650 Fax: 703-321-8547
4) Environmental Protection Agency
   Office of Research and Development
   National Center for Environmental Assessment

URL: http://www.epa.gov/records/a00148.html

Appendix 4. Glossary

A

Absorbed dose

the amount of a substance penetrating across the exchange boundaries of an organism, via physical or biological processes, after contact. The most common unit of dose is mg per kg body weight per day (mg/kg-day).

Absorption

the penetration of a substance into the body from the skin, lungs, or digestive tract.

Accuracy

the degree of agreement between a measured value and the true value, usually expressed as +/- percent of full scale.

Acute toxicity

any poisonous effect produced within a short period following exposure, usually up to 24-96 hours, resulting in biological harm and often death.

Administered dose:

the amount of substance given to a human or animal in dose response studies, especially through ingestion or inhalation (technically, it is an exposure, not a dose, because it does not account for absorption)

Advection

the horizontal movement of currents (e.g., the velocity of pollutants moving downstream or downwind).

Anchoring bias

the tendency to stabilize (or anchor) our probability estimates toward our first numerical estimate. Initial risk estimates serve as a reference point, but if that reference point is inaccurate, it can lead to bias in all the estimates that follow.

Applied dose:

the amount of substance given to a human or animal in dose response studies, especially through dermal contact. (technically, it is an exposure, not a dose, because it does not account for absorption)

Attributable risk:

the rate of a disease in exposed individuals that can be attributed to the exposure. This measure is derived by subtracting the rate (usually incidence or mortality) of the disease among non-exposed persons from the corresponding rate among exposed individuals.

Attrition bias (also called exclusion bias)

differences (between test and control group) in withdrawals from a study.

Availability bias

the ease of imagining or recalling an event. Risks that are easier to recall are likely to be perceived as having greater risk.

B

Background level

the level of pollution present in any environmental medium attributable to natural or ubiquitous sources.

Benchmark dose

the dose that induces a specific risk. For example, a benchmark dose could be developed for a 5% risk.

Bias

any difference between the true value and the actually obtained value that is due to all causes other than sampling variability.

Body burden

the total amount of a specific substance (for example, lead) in an organism, including the amount stored, the amount that is mobile, and the amount absorbed.

C

Carcinogen

a substance or agent that produces or incites cancerous growth.

Carcinogenic potency

the gradient of the dose-response curve for a carcinogen.

Case-control study

a study where individuals are distinguished by whether they do (cases) or do not (controls) have the disease being studied. The groups are then compared with respect to existing or past characteristics judged to be of possible relevance to the etiology of the disease.

Case-fatality rate

a ratio of the number of deaths due to a disease to the number of cases of that disease in a specified period. It expresses the frequency with which affected individuals die of the disease.

Chromatid

one of the pair of stands, formed by longitudinal splitting of a chromosome that are joined by a single centromere in somatic cells during mitosis; one of tetrad of strands formed by the lengthwise splitting of paired chromosomes during meiosis.

Chronic

having a persistent, recurring or long-term nature. As distinguished from acute.

Cohort study

see prospective study.

Comparative risk

an expression of the risks associated with two (or more) actions leading to the same goal; may be expressed quantitatively (a ratio of 1.5) or qualitatively (one risk greater than another risk).

Confidence interval

a range of values ($a1 < x < a2$) so chosen that, in repeated random samples from a population, an arbitrarily fixed percentage of that range will include the true value, x, of an estimated parameter. The limits, a1 and a2, are called confidence limits; the probability is called the confidence level. Confidence levels are commonly chosen as 0.05 or 0.01.

Confounding factors

variables that may introduce differences between cases and controls that do not reflect differences in the variables of primary interest.

Control group:

a group that is not exposed to a risky agent that is used for comparison with the test group (i.e., animals or humans).

Critical toxic effect

the most sensitive and specific biological change that is outside of acceptable physiological variation.

Cross-sectional study

an epidemiological study design in which measurements of cause and effect are made at the same point in time.

Cumulative probability distribution function

a function [$P(X<x)$] that expresses the probability that the actual or true risk X is less than an assumed value x. From the standpoint of calculus, the cumulative probability function is the integral of the probability distribution function.

D

Delivered dose:

the amount of substance available for interaction with any particular organ or cell (i.e., the target organ).

De minimis risk

from the legal maxim "de minimis non curat lex" or "the law is not concerned with trifles."

Deposition

the transfer of substances in air to surfaces, including soil, vegetation, surface water, or indoor surfaces, by dry or wet processes.

Detection bias (also called ascertainment bias and measurement bias)

differences between the comparison groups in outcome assessment.

Dispersion

a suspension of particles in a medium; the opposite of flocculation; a scattering process.

Dose

1. the amount of a substance available for metabolic processes of an organism following exposure and absorption into an organism.
2. the amount or concentration of undesired matter or energy deposited at the site of effect. See also absorbed dose.

Dose-response

a correlation between a quantified exposure (dose) and the percentage of a population that demonstrates a specific effect (response).

Dose-response assessment :

to determine the relation between the magnitude of exposure and the probability of occurrence of health effects in question.

E

Ecological fallacy

the inference that a correlation between variables derived from data grouped in social or other aggregates (ecological units) will hold between persons (individual units).

Effective exposure:

the exposure that leads to induction.

Environmental pathway

all routes of transport by which a toxicant can travel from its release site to human populations including air, water, and food chain.

Epidemiology

the study of the distribution and dynamics of diseases and injuries in human populations.

Eulerian perspective

a frame of reference used in environmental fate modeling in which the observer is fixed to the earth's surface. It can best be thought of as a map for pollutant location. This is distinguished from the Lagrangian perspective, in which the observer is fixed to the parcel or puff of pollutant.

Excess cases (or expected loss)

the quantity obtained by multiplying the magnitude of health or environmental effect loss by the probability (or risk) of that loss and adding the products. The expected loss is the average loss over a large number of trials; one must reflect on the appropriateness of its use in cases for which there will be only one, or a few, trials.

Exposure

the time integral of the concentration of a toxicant that is in the immediate vicinity of various ports of entry (such as lung, GI tract and skin). Qualitatively, it is the contact between a potentially harmful agent and a susceptible receptor (e.g., a human or other organism).

Exposure assessment

the process of measuring or estimating the intensity, frequency, and duration of human exposures to an agent currently present in the environment or of estimating hypothetical exposures that might arise from the release of new chemicals into the environment.

Extrapolation

in risk assessment, an educated guess based on observable responses and a mathematical model. The mathematical model is used to predict response levels that cannot be directly observed. All dose response models represent extrapolation.

F

False negative results

results that show no effect when one is there.

False positive results

results that show an effect when one is not there.

Finite difference equations

an approach to approximating the solution to the integration of complex differential equations. The basis for many models in environmental and occupational health is the use of non-linear equations that must be integrated by the use of calculus in order to answer various questions. Due to the complex nature of these equations, the only practical way to solve them is through the use of the finite difference approach, hence the name finite difference equations or finite difference models. The reader is referred to calculus textbooks for more discussion.

Food chain

dependence of a series of organisms, one upon the other, for food. The chain begins with plants and ends with the largest carnivores.

Framing bias

Risk estimates depend on whether the risk is expressed (or framed) as a gain or a loss.

G

Gaussian distribution model

A commonly used assumption about the distribution of values for a parameter, also called the normal distribution. For example, a Gaussian air dispersion model is one in which the pollutant is assumed to spread in air according to such a distribution and described by two parameters, the mean and standard deviation of the normal distribution.

H

Hazard

a condition or physical situation with a potential for an undesirable consequence, such as harm to life or limb.

Hazard assessment

an analysis and evaluation of the physical, chemical and biological properties of the hazard.

Hazard endpoint

a specific, observable change that constitutes the definition of a physiological or metabolic effect.

Hazard identification

1. to determine whether a particular agent is causally linked to particular health effects.
2. the process of determining whether exposure to an agent can cause an increase in the incidence of a health condition.

Hazard Index:

a measure of hazard for non-zero threshold toxicants, where any value greater than 1 is considered unacceptable. Technically, it is the actual dose divided by the reference dose, where actual dose is the maximum daily dose + background dose.

Health effect assessment

the component of risk assessment that determines the probability of a health effect given a particular level or range of exposure to a hazard.

Health risk

risk in which an adverse event affects human health.

Hydraulic conductivity

movement of water (usually measured in centimeters per second) that is caused by a hydraulic gradient.

Hydraulic gradient

the differences in water pressure that is the basis for groundwater studies.

I

Incidence

the number of new cases of a disease in a population over a period of time.

Individual risk

the risk to an individual rather than to a population.

Induction:

to stimulate a biological reaction

In vitro

outside the living organism.

In vivo

within the living organism.

Isopleth

lines on a graph connecting points of constant value; e.g., isopleths of concentration are lines of equal concentration.

J
K
L

Lagrangian perspective

a frame of reference used in environmental fate modeling in which the observer is fixed on a parcel or puff of pollutant. An analogy to this approach is driving a car down the highway: instead of studying movements from the standpoint of a pedestrian standing at the side of the road, the frame of reference is from the perspective of the driver of the car. This is distinguished from the Eulerian perspective, in which the observer is fixed to the earth's surface (much like the pedestrian standing at the side of the road).

Latency:

the time from induction to detected health effect

LOAEL:

lowest observed adverse effect level

Latency period

the time from exposure to an agent to the onset of a health effect.

Lethal dose fifty (LD50)

a calculated dose of a chemical substance that is expected to kill 50% of a population of experimental animals exposed through a route other than respiration. Dose is usually expressed in milligrams per kilogram of body weight.

Logit model

a dose-response model that, like the probit model, leads to an S-shaped dose-response curve, symmetrical about the 50% response point.

Log-probit model

a dose-response model that assumes each animal has its own threshold dose, below which no response occurs and above which a tumor [or other effect] is produced by exposure to a chemical.

M

Mass balance (also called conservation of mass).

the assumption that the mass in any compartment is a balance of mass entering, mass exiting, and mass already present in the compartment. There may be numerous sources for entrance and exit, including transport, transfer, and transformation. Mass balance is the basis for many environmental fate and biokinetic models.

Maximum tolerated dose (or MTD)

the maximum dose that does not lead to acute effects.

Multistage model

a carcinogenesis dose-response model where it is assumed that cancer originates as a "malignant" cell, which is initiated by a series of mutations occurring in finite steps.

Mutagen

a substance that can induce alterations in the DNA of either somatic or germinal cells.

N

NOAEL:

no observed adverse effect level

NOEL:

no observed effect level

Null hypothesis:

in statistical tests, the hypothesis that there is no difference between the test group and control group.

O

Oncogenic

a substance that causes tumors, whether benign or malignant.

One-hit model

the basic dose-response model based on the concept that a tumor can be induced by a single receptor that has been exposed to a single quantum or effective dose unit of a chemical.

P

Performance bias

differences in the care provided to the participants in
the comparison groups other than the intervention under investigation.

Plume

the cloud of steam or smoke that comes from a chimney stack and blows downwind. Also, the contaminated portion of groundwater that moves past a source of pollution.

Population at risk

a limited population that may be unique for a specific dose-effect relationship; the uniqueness may be with respect to susceptibility to the effect or with respect to the dose or exposure itself.

Potency

the slope of the dose-response curve for a carcinogen
(in this book, the value of R).

Precision

a measure of how consistently the result is determined by repeated determinations without reference to any "true" value.

Prevalence

the number of existing cases in a population who have the disease at a given point (or during a given period) of time.

Probability density function

a function that expresses the percentage of time that a variable falls within any given range (see also Cumulative probability function).

Probit analysis

a statistical transformation that will make the cumulative normal distribution linear. In analysis of dose-response, when the data on response rate as a function of dose are given as probits, the linear regression line of these data yields the best estimate of the dose-response curve. The probit unit is $y = 5 + Z(p)$, where p = the prevalence of response at each dose level and $Z(p)$ = the corresponding value of the standard cumulative normal distribution.

Prospective study

a study where individuals are distinguished by whether they are or are not exposed to certain factors, and then followed over time to determine differences in the rate at which disease develops in relation to exposure to the factor. Also called cohort study.

Q
R

Random error

indefiniteness of result due to finite precision of experiment. Measure of fluctuation in results upon repeated experimentation.

Rate

in epidemiology, the frequency of a disease or characteristic expressed per unit of size of the population or group in which it is observed. The time at or during which the cases are observed is a further specification.

Reference dose

the daily dose with no significant risk over a lifetime. Generally applied to non-carcinogens.

Relative potency

a comparison of the potency of two or more reference chemicals.

Relative risk

the ratio of the rate of the disease (usually incidence or mortality) among those exposed to the rate among those not exposed.

Reproducibility

the degree of variation obtained when the same measurement is made with similar instruments and many operators.

Representativeness bias

the similarity of new events to older known processes (the older processes are thought to be representative of the new events).

Response

the percentage of a population that demonstrates a specific effect. May also refer to the nature of the effect.

Retrospective study -- See case-control study.

Risk

1. the possibility of suffering harm or loss.
2. the probability and magnitude of a hazard.
3. the potential for realization of unwanted, adverse consequences to human
4. life, health, property, or the environment; estimation of risk is usually based on the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred.

Risk analysis

1. A collection of approaches and disciplines devoted to all aspects of risk issues (includes risk assessment, risk communication, and risk management).
2. A detailed examination including risk assessment, risk evaluation, and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property, or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks.

Risk assessment

1. the characterization of adverse effects from exposure to hazards. (characterization includes probability, uncertainties, analytic techniques, and models)
2. The process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment.

Risk characterization

to describe the nature and often the magnitude of human risk, including attendant uncertainty.

Risk communication

an interactive exchange of information and opinions among individuals, groups, and institutions regarding risk.

Risk evaluation

a component of risk assessment in which judgments are made about the significance and acceptability of risk.

Risk group

a group for which a risk assessment is being performed (i.e., humans).

Risk management:

the evaluation, selection, and implementation of alternative risk control actions.

S

Screening risk assessment

a risk assessment that relies on relatively simple models and limited data.

Selection bias

differences in baseline characteristics because of the way participants were selected or assigned. It is also used to mean that the participants are not representative of the population of all possible participants.

Sensitivity (or "sensitivity to intervention")

the ability to lower, eliminate, or otherwise manage risks.

SMR

see "Standardized mortality ratio."

Stack emissions

effluents released into the atmosphere from the exhaust flue of a building; usually refers to pollutants but can refer to steam or other nonpolluting effluents.

Standard deviation

a measure of dispersion or variation, usually taken as the square root of the variance.

Standardized mortality ratio (SMR)

the ratio of observed deaths in a population to the expected number of deaths as derived from rates in a standard population with adjustment of age and possibly other factors such as sex or race.

Statistical bias

any systematic distortion away from the "truth." Includes selection bias, performance bias, attrition bias, and detection bias.

Statistical error

type 1 = false rejection of the null hypothesis
type 2 = false acceptance of the null hypothesis
type 3 = asking the wrong question
type 4 = wrong method
type 5 = wrong action

Statistical significance

the statistical significance determined by using appropriate standard techniques of statistical analysis with results interpreted at the stated confidence level and based on data relating species which are present in sufficient numbers at control areas to permit a valid statistical comparison with the areas being tested.

Steady state exposure

exposure to an environmental pollutant whose concentration remains constant over time.

Synergism

an interaction between two substances that results in a greater effect than both of the substances could have had acting independently.

Synergistic effects

joint effects of two or more agents, such as drugs that increase each other's effectiveness when taken together.

Systematic error

a reproducible inaccuracy introduced by faulty equipment, calibration, or technique.

T

Test group

a group that is exposed to a risky agent in an experimental environment (i.e., test animals, or humans in a "natural experiment"); also called experimental group.

Threshold

a pollutant concentration (or dose) below which no deleterious effect occurs.

Threshold dose

the minimum application of a given substance required to produce an observable effect.

Topography

the detailed delineation of the geographic features of a locality.

Transfer

in environmental fate modeling, (to air and soil), the movements of pollutants between different media (e.g., between water, air, and soil).

Transformation

in environmental fate modeling, the change in the physical or chemical structure of a pollutant (e.g., oxidation, photolysis, oxidation, and the chemical interaction of pollutants).

Transport

in environmental fate modeling, the physical movement of pollutants (e.g., wind, water flow, adsorption).

Type 1 (or alpha) statistical error

false *rejection* of the null hypothesis.

Type 2 (or beta) statistical error

false *acceptance* of the null hypothesis.

Type 3 statistical error

asking the wrong question in statistical analysis.

type 4 statistical error

using the wrong method to answer a statistical question (e.g., using chemical analysis to resolve a psychological question, or vice-versa).

type 5 statistical error

reaching the wrong policy conclusion from statistical analysis (sometimes described as the right diagnosis followed by wrong medicine, or as good science followed by bad policy).

U

Uncertainty analysis

a detailed examination of the systematic and random errors of a measurement or estimate; an analytical process to provide information regarding the uncertainty.

V

Vadose zone (also called unsaturated zone)

the region between the atmospheric and saturated zone. The atmospheric zone begins at ground level (i.e., where the atmosphere begins). The saturated zone begins at the water table, and generally refers to an aquifer composed of sand and gravel with water saturating the pores. The vadose zone is the basis for most groundwater models.

W

Watershed

land area from which water drains toward a common watercourse in a natural basin.

X

Y

Z

Zero order analysis

the simplest approach to quantification of a risk with a limited treatment of each risk component (e.g. source terms, transport, health effects, etc.).

Appendix 5. Useful web sites

The web site that corresponds with this book is at:

http://www.csun.edu/~vchsc006/469/risk.html

Other useful sites for calculations are at:

Normal table
http://www.math.com/tables/stat/distributions/z-dist.htm

Poisson
http://members.aol.com/johnp71/confint.html

Calculator with printout
http://www.k4web.com/webdesign/calculator.htm

Screen3
http://www.eyeol.com/screen3/screen3.cfm

Gauss
http://www.industrialhygiene.com/calc/model.html

chi square
http://www.georgetown.edu/cball/webtools/web_chi.html

Some other potentially useful glossaries are:

Atmospheric Chemistry and Air Quality Glossary
http://www.shsu.edu/~chemistry/Glossary/glos.html

Air Quality Glossary
http://www.teleport.com/~hanrahan/glossary.htm#critpol

WATERSHEDDS Glossary
http://h2osparc.wq.ncsu.edu/info/glossary.html

Water Quality Association Glossary of Terms
http://www.wqa.org/WQIS/Glossary/GlossHome.html

Integrated Risk Information System
http://www.epa.gov/iris/gloss8.htm

EPA Superfund: glossary of risk terms
http://www.epa.gov/superfund/programs/risk/glossary.htm

Appendix 6. Summary of Equations

1. $$z = \frac{Pt - Pc}{\sqrt{pq\left(\frac{1}{Nt} + \frac{1}{Nc}\right)}}$$

where:

Nt = total number in test group
Nc = total number in control group
Xt = cases in test group
Xc = cases in control group
Pt = Xt/Nt = risk to test group
Pc = Xc/Nc = risk to control group
p = [Xt + Xc] / [Nt + Nc]
q = 1-p

2. $$\chi \equiv \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left[(y/\sigma_y)^2 + (z/\sigma_z)^2\right]\right]$$

where:

χ = concentration at any point in the x, y, z coordinate space (kg/m^3)
Q = emissions (kg/sec)
u = average wind speed (meters/sec)
σ_y = ("sigma-y") standard deviation of dispersion in the y direction (meters)
σ_z = ("sigma-z") standard deviation of dispersion in the z direction (meters)
x = distance downwind (meters)
y = distance crosswind (meters)
z = vertical direction (meters)

3. $$E = \sum_{i} fi\ Ci$$

where:

E = exposure
i = micro-environments
f = fraction of time
C = pollutant concentration

4. $$D = \frac{C}{F} * I * \frac{70}{W} * \frac{E}{L} * T$$

where:

D = dose
C = ambient concentration (in air, water, etc.)
F = safety factors (discussed below)
I = intake (breathing, drinking,etc.)
70 = assumed weight of average human
W = weight of test animal (W = 70 for human subjects)
E = average time of exposure (usually in days)
L = average lifetime of species (usually in days)
T = lifetime of exposure in humans (usually 75 * 365 days)

5. Pe' = [Pt' -Pc] / [1 - Pc].

where:

Pe' = statistical upper limit of the adjusted excess risk
Pt' = statistical upper limit of the risk to the test group
Pc = risk to the control group

6. $R = Pe' / CIT$

where:

R = risk factor (slope of line) (excess risk per unit of dose)
Pe' = statistical upper limit of the adjusted excess risk
C = ambient concentration (in air, water, etc.)
I = intake (breathing, drinking,etc.)
T = lifetime of exposure in humans (usually 75 * 365 days)

7. **$P = R D = R C I T$**

where:

P = response (individual excess risk)
R = risk factor
D = individual dose = C I T

8. **$EC = P N = R D N = R C I T N$**

where:

EC = excess cases
N = population at risk
P = risk

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